PB90-167396

Report to Congress on Indoor Air Quality. Volume 2 Assessment and Control of Indoor Air Pollution

(U.S.) Environmental Protection Agency, Washington, DC

Aug 89

U.S. Department of Commerce
National Technical Information Service
NTIS

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. EPA/400/1-89/001C

2.

3. Recipient's Accession No. PB90 167396/AS

4. Title and Subtitle

Report to Congress on Indoor Air Quality (Executive Summary;
Volume I: Federal Programs Addressing Indoor Air Quality;
~~Volume II: Assessment and Control of Indoor Air Pollution;~~
Volume III: Indoor Air Pollution Research Needs Statement)

5. Report Date August 1989

6.

~~7. Author(s)~~

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

Office of Air and Radiation/Office of Research and Development
U.S. Environmental Protection Agency
401 M Street S.W.
Washington DC 20460

13. Type of Report & Period Covered Final

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This is a three volume report plus executive summary with recommendations that fulfills the reporting requirement of Title IV Section 403(e) of the Superfund Amendments and Reauthorization Act of 1986. The report contains a description of the research and program activities in Federal agencies; a comprehensive overview of the current level of knowledge and uncertainties associated with the issue of indoor air quality; and an identification of the major gaps and research needs in indoor air quality.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement Release unlimited

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages 252

22. Price A12

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

PB90-167396

United States
Environmental Protection
Agency

Office of Air and
Radiation
(ANR-445)

August 1989

EPA/400/1-89/001C

EPA

Report to Congress on Indoor Air Quality

Volume II: Assessment and Control of Indoor Air Pollution

Issued under Section 403(e), Title IV of the Superfund Amendments and Reauthorization Act of 1986 (SARA)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

REPORT TO CONGRESS
ON
INDOOR AIR QUALITY

VOLUME II: ASSESSMENT AND CONTROL OF INDOOR AIR POLLUTION

Issued Under
Section 403 (e), Title IV
of the
Superfund Amendments and Reauthorization
Act (SARA) of 1986

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Washington, D. C. 20460

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PREFACE

INTRODUCTION

Total human exposure to environmental contaminants is the composite of exposure to the air we breath, the water we drink, the food we eat, and the physical contact we have with our surroundings. The air we breath is a major component of this exposure and, since the majority of people in industrialized societies spend most of their time indoors, an examination of the indoor air environment and its attendant affects on human health is an important public undertaking.

EXPOSURE AND BUILDING PERSPECTIVES

Individuals are exposed to a variety of indoor air pollutants as they progress through a succession of microenvironments during the course of their daily activities. The environment at home, in transit, at school, at work, and in recreational facilities all contribute to an individual's total exposure. The contribution of each microenvironment is proportional to both the time spent and the pollutant concentration in that microenvironment.

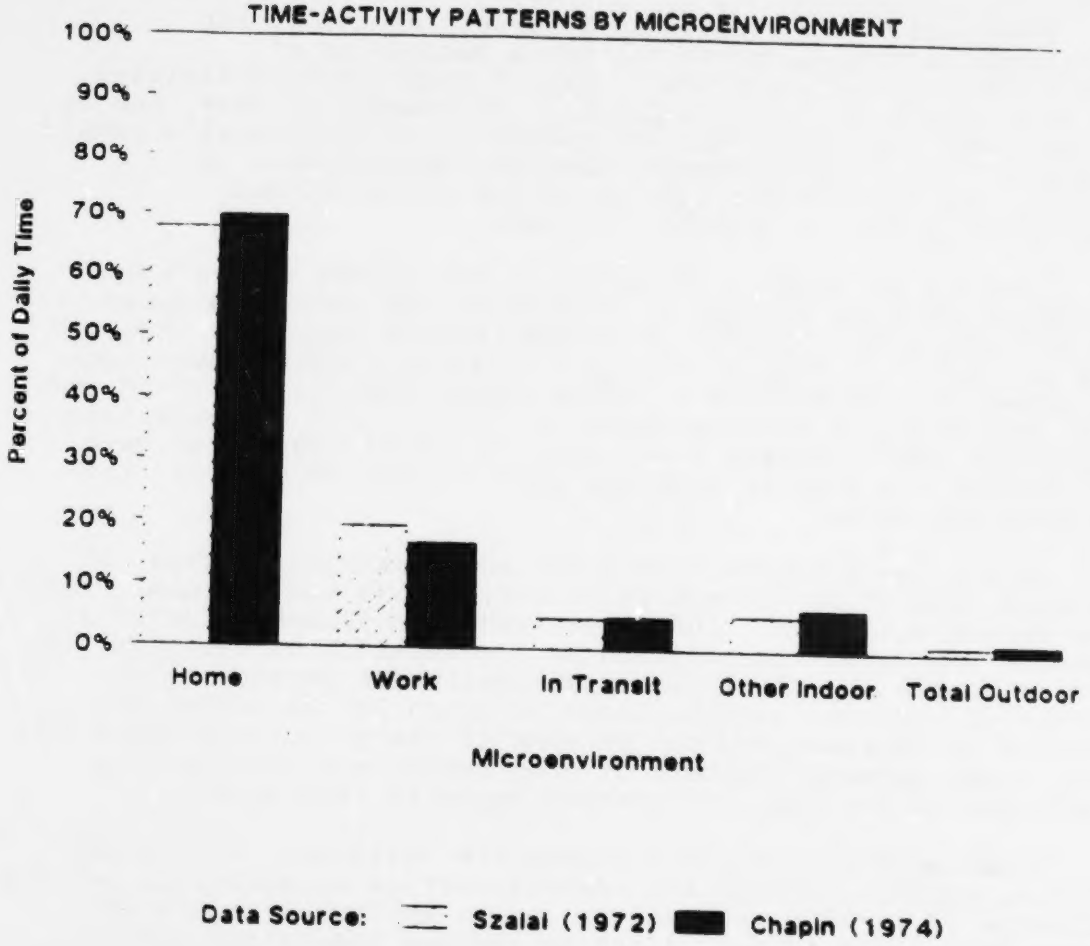
Time budget studies conducted in the United States and Europe reveal that persons in industrialized countries spend over 90% of their time indoors. The most notable published time-use data are those by Chapin (1974), and Szalai (1972); these data are summarized in Exhibit 1. More recent work by Ott (1982 and 1988) has analyzed the previously published data and incorporated results of EPA-sponsored field studies; these aggregated data corroborate the earlier findings with respect to typical time-activity patterns.

People spend approximately 93% of their time indoors, 2% outdoors, and 5% in transit (e.g. car, train, bus). Thus, from a time budget standpoint, indoor environments dominate the total exposure spectrum. In addition to the duration of exposure, the adverse health impact of indoor air pollution depends on a variety of factors, not the least of which is the number and strength of sources, and the potency of the pollutants which they emit. Thus, several chapters of this report are devoted to a discussion of sources, pollutants, exposure, and risk.

Since most indoor environments are buildings (residences, offices, schools, etc.), the characteristics of buildings and the influence of building systems on indoor environments are of utmost importance in any effort to address indoor air quality. Buildings, in the broadest sense, are enclosed spaces that provide refuge and shelter from the exterior environment. Modern buildings perform this function extremely well. One important implication of this is that building systems create and control interior environments, so that the health, comfort, and productivity of building occupants is greatly influenced by the design, operation, and maintenance of building systems. Accordingly, interspersed throughout the report are discussions which reflect the importance of building systems to indoor air quality, and the role of proper building design and management to the prevention and mitigation of indoor air pollution problems.

EXHIBIT 1

TIME-ACTIVITY PATTERNS BY MICROENVIRONMENT



ORGANIZATION

This document is organized in two parts. Part I, entitled, **Assessing Health and Economic Impacts of Indoor Air Pollution,** characterizes the nature and magnitude of indoor air pollution problems in terms of both the exposure and buildings contexts discussed in the preface. Part II, entitled **Controlling Indoor Air Pollution,** addresses controls in terms of the engineering and operational methods, as well as the legislative and policy instruments, that are available or that may be developed for use in both the public and private sectors.

Part I begins with a discussion of building systems and factors that affect concentrations of indoor air pollutants. It outlines the factors, including building system components, and discusses the importance of building design and management practices. The chapter also provides limited data on the U.S. building stock, and lays the foundation for the discussion of mitigation and control strategies which is presented in Chapter 6

Chapters 2 through 5 characterize the health and economic impact of indoor air pollution. Chapter 2 identifies the major pollutants, and sources, and discusses measuring and modeling capabilities, practices, and limitations. Chapter 2 also discusses the results of some important indoor air and personal exposure monitoring studies. Chapter 3 provides an overview of non-carcinogenic health effects and provides information on populations with particular sensitivity to indoor pollutants. Chapter 4 presents a discussion of carcinogenic risk assessments for several indoor air pollutants.

Chapter 5 presents a brief assessment of the economic impacts of indoor air pollution, using, in part, information provided in the health effects component of this report. The analysis examines the costs of damage to equipment and materials, as well as the costs of illness and lost productivity.

Part II of the report begins with Chapter 6 which covers engineering and operational methods of control. This chapter also contains a discussion of protocols for diagnosing indoor air quality problems, and of policy options for implementing the control methods.

Chapter 7 presents available standards and guidelines in both the public and private sector, and assesses their applicability to non-industrial indoor environments.

Chapter 8 assesses the applicability of available federal legislative authorities to the control of indoor air pollution.

Chapters 9 and 10 conclude the report with assessments of indoor air programs and policy issues.

REFERENCES

Chapin, F.S. 1974. Human Activity Patterns in the City. New York: John Wiley and Sons.

Ott, W.R. 1982. Human Activity Patterns: A Review of the Literature for Estimation of Exposures to Air Pollution. Draft Report, U.S. EPA.

Ott, W.R. 1988. Human Exposure to Environmental Pollutants. Presented at the 81st Meeting of the Air Pollution Control Association, Dallas, TX, June 20-24.

Szalai, A. 1972. The Use of Time: Daily Activities of Urban and Suburban Populations in Twelve Countries. The Hague, Paris: Mouton.

PART I

Assessing
the
Health and Economic Impacts
of
Indoor Air Pollution

CHAPTER 1 - BUILDING SYSTEMS AND FACTORS AFFECTING INDOOR AIR QUALITY

This chapter characterizes the building stock and describes the factors that affect indoor air quality and how these factors are influenced by the design, operation, and maintenance of building systems. By way of illustration, the chapter includes a discussion of indoor air quality problems that have resulted from building system inadequacies.

1.1 CHARACTERISTICS OF THE U.S. BUILDING STOCK

The following paragraphs discuss some of the characteristics of the building stock of the U.S. that are relevant to indoor air quality. These include general characteristics, heating and cooling systems used, and the characteristics of the building shell that affect air exchange rates. Except as otherwise noted, all data reflect 1984 levels for housing and 1983 levels for commercial buildings as reported by the U.S. Department of Energy (1986 and 1985).

Residential

General Characteristics

Exhibit 1-1 presents information on the general characteristics of the stock of housing units in the U.S. In 1984, the U.S. residential housing stock was comprised of 86 million occupied units (U.S. Department of Energy, 1986). These units had a total floor space of 144 billion square feet, an average of 1672 square feet per housing unit. Most of the housing units in the U.S., with over three-quarters of all residential floor space, are detached single-family dwellings. About half as many units are in apartment and condominium buildings containing two or more housing units. Just under six percent of U.S. residences are mobile homes. Half of these mobile homes are in the South census region (Amols *et al*., 1988).

Heating and Cooling Characteristics

Exhibit 1-1 illustrates the distribution of heating and cooling system types in U.S. residences. The type of heating appliance(s) and fuel(s) used in the residence can exert significant effects on indoor air quality; products of combustion are commonly found at significant concentrations in residences equipped with unvented heating units. In addition, many multifamily residential buildings have central forced-air heating and cooling systems, wherein the quality of the indoor atmosphere is influenced by the introduction and circulation of outside air into the occupied spaces of the building. (These issues are discussed more completely in a subsequent chapter.)

Exhibit 1-1

Residential Building Stock Characteristics a/

	Number of Housing Units (million)	Percent of All Units	Percent of Total Floor Space	Comments
TOTAL U.S. HOUSING UNITS	86.3	100.0	100.0	
TYPE OF STRUCTURE				
Single-Family				
Detached	53.5	62.0	76.0	
Attached	4.1	4.7	5.3	
Mobile Home	5.1	5.9	3.0	
Multifamily				
2 to 4 Units	10.0	11.6	8.0	
5 or More Units	13.6	15.7	7.7	
HEATING SYSTEMS				
Central Warm-Air Furnace	40.8	47.3	53.3	
Steam or Hot-Water System	15.0	17.4	16.6	
Room Heater/Other	9.3	10.8	8.2	
Built-In Electric Unit	5.4	6.3	5.0	
Wood Stove	5.7	6.6	7.1	
Heat Pump	3.1	3.6	3.7	
Gas Floor, Wall, or Pipeless Furnace	5.6	6.5	4.5	
PRIMARY HEATING FUEL				
Natural Gas	47.8	55.4	56.5	
Electricity	14.5	16.8	14.6	
Fuel Oil	10.7	12.4	14.1	
Wood	6.5	7.5	8.4	
LPG	3.9	4.5	3.6	
Kerosene	1.5	1.7	1.2	
Other	0.9	1.0	1.3	
None	0.6	0.7	0.4	
COOLING SYSTEMS				
Room Air-Conditioner	26.8	31.0		
Central Air-Conditioner	24.6	28.5		
WEATHER ZONES				Heating degree days (HDD) and cooling degree days (CDD) are measures of the heating and cooling effort, respectively, required to maintain thermal comfort indoors.
HDD > 7000	9.0	10.4	11.6	
5500 < HDD < 7000	21.5	24.9	28.6	
4000 < HDD < 5499	22.5	26.1	27.3	
HDD < 4000	20.0	23.1	19.8	
CDD > 2000	13.3	15.4	12.7	
WEATHERIZATION EFFORTS (Single-Family Units Only)				Weatherization efforts affect indoor air quality by restricting the flow of heat and air through the building shell.
Weatherstripping or Caulking	39.9	69.3		
Roof or Ceiling Insulation	45.2	78.5		
Wall Insulation	30.8	53.4		
Floor Insulation	5.5	9.6		
Combination of Storm Windows and Doors and Roof/Ceiling Insulation	29.6	51.3		
No Weatherization	5.8	10.0		

---

a/ From U.S. DOE, 1986. RECS: Housing Characteristics, 1984, Energy Information Administration, DOE/EIA-0314(84).

A large percentage of domestic housing units are heated by the combustion of natural gas, fuel oil, LPG, kerosene, or wood, all of which produce air pollutants that can potentially degrade the quality of the indoor atmosphere. Multi-family dwellings are more often heated with fuel oil and natural gas than the housing stock in general, which is dominated by single-family dwellings. Mobile homes, on the other hand, use electricity and liquified petroleum gas (LPG) more regularly than other housing types.

Thermal Characteristics

Exhibit 1-1 presents data on the thermal characteristics of U.S. residences. Most of the residential stock of the U.S. is in relatively mild climates with less than 2000 cooling degree days (CDD) per year and less than 7000 heating degree days (HDD) per year.[1] Nevertheless, ninety percent of all single-family housing units have incorporated some type of weatherization material. Weatherization efforts (e.g., insulation, storm doors and windows, and weatherstripping) influence indoor air quality by altering the flow of heat and air through building shells; tightened buildings can lead to increased indoor air pollution levels, unless ventilation is increased.

Ventilation Characteristics

Air exchange rates due to infiltration were measured in two national surveys of houses (Diamond and Grimsrud, 1983). The first involved a sample of 312 new houses in the U.S. and Canada. Infiltration rate measurements were taken over the heating season from November through March. The mean value of the seasonal averages for all houses was 0.63 air changes per hour; however, since the distribution was skewed, the median value of 0.50 air changes per hour may be more representative.

Air exchange rates due to infiltration were also measured in a second survey involving a sample of 266 low income houses. Single measurements, rather than seasonal averages, were taken for each house. The mean air exchange rate from these measurements was 0.9 air changes per hour. The higher air exchange rate results because the houses are older and of poorer construction (Diamond and Grimsrud, 1983).

---

[1] Heating degree days and cooling degree days are measures of the heating and cooling effort, respectively, required to maintain thermal comfort indoors. High values of HDD indicate large heating requirements; high values of CDD indicate large cooling requirements. For example, Detroit averages about 7000 HDD per year, New York about 5500 HDD per year, Nashville about 4000 HDD per year, and Memphis about 2000 CDD per year.

Commercial

General Characteristics

Exhibit 1-2 presents some general characteristics of commercial buildings in the U.S. In 1983 there were 3.9 million commercial buildings (defined as all non-industrial and non-residential structures) in the U.S. (U.S. Department of Energy, 1985). These units have a total floor space of 52 billion square feet, an average of 13,300 square feet per building. Commercial buildings have a variety of uses; these uses determine the populations likely to enter their indoor microenvironments. Over one-quarter of all commercial buildings in the U.S. are for mercantile or service uses. Other uses of commercial buildings, in decreasing order of number of buildings, include offices, assembly, warehouses, food sales and service, vacant, residential, educational, lodging, and health-care. Educational and health-care structures are on the average the largest types of buildings, and food sales and service and mercantile and service are the smallest. Most commercial buildings have only one floor, and less than one-fifth of all commercial buildings have three or more floors.

Most commercial buildings house a single establishment. Government-occupied buildings represent almost 9 percent of all U.S. commercial buildings; these buildings account, however, for nearly 20 percent of the country's commercial floor space.

Heating and Cooling Characteristics

Exhibit 1-2 presents data on the heating and cooling of commercial buildings in the U.S. Over sixty percent of all commercial buildings are fully heated and almost half of the rest are partially heated. Two-thirds of all commercial buildings in the U.S. are at least partially cooled. Almost one-half of all commercial buildings are heated by forced-air central systems, and a similar percentage are centrally cooled. Air-distributing heat and cooling systems are most prevalent in office and assembly buildings. Heating systems which do not actively distribute air are found in more than half of the country's commercial buildings (especially structures other than office buildings and places of assembly).

Thermal and Energy Use Characteristics

Exhibit 1-2 presents data on the thermal and energy use characteristics of the U.S. commercial building stock. Roughly three-quarters of the commercial building stock is in moderate climates. Nevertheless, some energy conservation features, such as roof/ceiling insulation, wall insulation, and special glass are used in over two-thirds of all commercial buildings. However, just over 10 percent of these buildings incorporate all three of these features. Insulation and special glass use in

Exhibit 1-2

Commercial Building Stock Characteristics a/

	Number of Buildings (thousands)	Percent of All Buildings	Percent of Total Floor Space	Average Floor Space (1000 sq. ft.)	Comments
TOTAL	3948	100.0	100.0	13.3	Total Floor Space = 52.3 billion sq. ft.
PRINCIPLE ACTIVITY					Building type influences the nature and duration of typical occupant exposures. The heating, cooling, and thermal characteristics presented below are related in part to building type. (See text for discussion.)
Assembly	457	11.6	10.5	12.0	
Educational	177	4.5	11.5	34.2	
Food Sales/Service	380	9.6	3.9	5.4	
Health Care	61	1.5	4.4	37.6	
Lodging	106	2.7	4.3	21.1	
Mercantile/Services	1071	27.1	19.9	9.7	
Office	575	14.6	16.2	14.7	
Residential	236	6.0	4.7	10.4	
Warehouse	425	10.8	13.0	16.0	
Other	179	4.5	5.3	15.4	
Vacant	281	7.1	6.4	11.9	
BUILDING OCCUPANTS					Number and type of establishments in commercial buildings influence the relative effort required to identify and address indoor air quality problems.
Single Establishment	3160	80.0	67.3	11.1	
Multi-Establishment	645	16.3	29.8	24.2	
Government Occupant	346	8.8	19.3	29.2	
Non-Government Occupant	3640	91.2	80.7	11.7	
THERMAL CONDITIONING					
Heated	3508	88.9			
Entire Building	2427	61.5			
Part of Building	1081	27.4			
Cooled	2643	66.9			
Entire Building	1129	28.6			
Part of Building	1514	38.3			
HEATING SYSTEM					
Central Forced-Air	1858	47.1			
Other Central	998	25.3			
Self-Contained	583	14.8			
COOLING SYSTEM					
Central Forced-Air	1748	44.3			
Self-Contained	1263	32.0			
Heat Pump	169	4.3			

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a/ From U.S. Department of Energy. 1985. Nonresidential Building Energy Survey: Characteristics of Commercial Buildings, 1983. Energy Information Administration. DOE/EIA-0246(83).

Exhibit 1-2 (continued)

Commercial Building Stock Characteristics a/

	Number of Buildings (thousands)	Percent of All Buildings	Percent of Total Floor Space	Average Floor Space (1000 sq. ft.)	Comments
HEATING FUEL					
Electricity	1105	28.0			
Natural Gas	2011	50.9			
Fuel Oil	566	14.3			
Propane	161	4.1			
Steam	55	1.4			
Wood	115	2.9			
Coal	48	1.2			
Other	38	1.0			
COOLING FUEL					
Electricity	2515	63.7			
Natural Gas	141	3.6			
Other	21	0.5			
WEATHER ZONES					Heating degree days (HDD) and cooling degree days (CDD) are measures of the heating and cooling effort, respectively, required to maintain thermal comfort indoors.
HDD > 7000	421	10.7	10.9		
5500 < HDD < 7000	1153	29.2	32.4		
4000 < HDD < 5499	1016	25.7	26.4		
HDD < 4000	678	17.2	14.3		
CDD > 2000	679	17.2	16.0		
ENERGY CONSERVATION FEATURES					Weatherization practices reduce the flow of air and heat through the building shell.
Roof/Ceiling Insulation Only	571	14.5			
Special Glass Only	410	10.4			
Wall Insulation Only	223	5.6			
Roof/Ceiling and Wall Insulation	444	11.2			
Roof Ceiling and Special Glass	379	9.6			
Wall Insulation and Special Glass	189	4.8			
All Three Features	510	12.9			

a/ From DOE. 1985.

Exhibit 1-2 (continued)

Commercial Building Stock Characteristics a/

	Number of Buildings (thousands)	Percent of All Buildings	Percent of Total Floor Space	Average Floor Space (1000 sq. ft.)	Comments
MAINTENANCE AND CONTROL OF HEATING AND COOLING SYSTEM					
Computerized Control	105	3.0			
Occupant Control					Occupant control allows personal comfort adjustments.
Heating	2541	72.4			
Cooling	1170	44.3			
Regular HVAC Maintenance	2914	81.9			Maintenance improves indoor air quality by correcting ventilation deficiencies and removing potential sources.
Reduced System Operation in Off Hours					Reduced system operation in off hours allows pollutant concentrations to build up and create potential human exposure problems upon re-occupancy.
Heating	3010	85.8			
Cooling	2302	87.1			

---

a/ From DOE. 1985.

building construction are far more prevalent in new buildings than in old.

Only a very small fraction of all mechanically heated and cooled commercial buildings in the U.S. have computerized control of heating and cooling. Most heated buildings under 10,000 square feet allow occupant control of heating and cooling.

Most heated and cooled buildings have regular HVAC system maintenance programs; the proportion of buildings with such programs increases as building size increases. About 70 percent of buildings under 5000 square feet have regular maintenance while nearly all buildings above 200,000 square feet have such programs. HVAC maintenance can be a critical influence on indoor air quality.

Ventilation Characteristics

Whole building ventilation rates measured in 38 commercial buildings in the Pacific North West ranged from 0.3 to 4.2 air changes per hour, with an average of 1.5 air changes per hour (Turk et al., 1988). Ventilation rates from a comprehensive study of 14 commercial buildings, involving 3000 measurements over a period in the order of one year have also been reported (Persily, 1989). The mean values for each building ranged from 0.29 to 1.73 air changes per hour. The mean of all buildings was 0.94 and the median value was 0.89 air changes per hour.

1.2 FACTORS AFFECTING INDOOR AIR QUALITY

Concentrations of pollutants in the indoor air are determined by (1) the indoor source emission rates (including the rate of entry from soil gases), (2) the rate at which indoor air is exchanged with outdoor air, (3) the concentrations of pollutants in the outdoor air, and (4) rates at which pollutants are removed from or chemically transformed in the indoor environment. These factors will be discussed in turn.

Source Emissions

Concentrations of contaminants indoors depend most importantly on the strength of the emissions from contributing sources. Indoor sources include building materials, furnishings, combustion devices, a variety of consumer and commercial products, as well as human occupants and their pets. Emission rates of volatile organic compounds from building materials, furnishings, and some commercial and consumer products often increase under conditions of high temperature and humidity, but generally decrease with age. Emissions of particulate matter and combustion gases from combustion appliances such as stoves and space heaters depend on design, fuel, and use factors. Generally, vented appliances pollute less than unvented ones; gas appliances tend to burn more cleanly than liquid or solid fuel devices, and proper use and maintenance of the device is essential to controlling emissions (Tucker, 1987). Bioeffluents from people and their pets, as well as microbial contamination of humidification systems and water damaged materials can normally be adequately controlled with proper hygiene and maintenance practices.

Radon and other soil gases enter the indoor environment through cracks and other openings in the building foundation when the air pressure in the structure is lower than it is in the soil. The rate of entry depends on the concentration in the soil, the permeability of the soil, and the pressure difference between the soil gas and the air in the structure, and the characteristics of the structure itself.

Air Exchange Rate and Outdoor Concentrations

Outdoor air can be exchanged for indoor air through natural ventilation, mechanical ventilation, or through infiltration and exfiltration. Natural ventilation occurs when desired air flows occur through windows, doors, chimneys, and other building openings. Mechanical ventilation is the mechanically induced movement of air through the building. Mechanical systems usually condition and filter the air, and allow for the entry of outdoor air through outdoor air dampers. Infiltration and exfiltration are the unwanted movement of air through cracks and openings in the building shell. A "tight" building is one in which infiltration and exfiltration rates are very low.

The air exchange rate of a building affects indoor air quality in two ways. First, it determines the extent to which outdoor air can dilute or replace indoor air and prevent indoor air pollutants from accumulating to high levels. The extent to which air exchange is effective in diluting indoor pollutants also depends on how well outdoor air is mixed with indoor air.

Ventilation effectiveness is a measure of the portion of outdoor air brought into a building that reaches the breathing zone of the occupants. If, for example, outdoor air which is brought into the building is short-circuited directly out the exhaust, inadequate air quality can result regardless of the overall air exchange rate. Building layout, occupant activities, and the location of supply and return registers can all influence the effective circulation of ventilation air.

However, bringing in outdoor air also brings in the pollutants it contains. Thus, the second effect of air exchange on indoor air quality is to contaminate the indoor air with outdoor pollutants. As a general rule, outdoor air concentrations, particularly in buildings with high air exchange rates, will act as the background level for the indoor environment. This is normally not a problem where ambient outdoor levels are acceptable and no major sources exist in the immediate vicinity of the building. Indoor sources will increase concentrations above this level, while pollutant removal mechanisms will lower them.

Removal Mechanisms

Pollutant removal mechanisms will lower indoor concentrations and improve indoor air quality. Pollutants can be removed from the outdoor air prior to entering the indoor space, or they may be removed directly from the indoor environment. Removal mechanisms may be physical or chemical. They may be part of the natural reaction of the chemical with its surroundings, or they may be deliberately incorporated into the building operating system. Air filtration devices are examples of a physical removal mechanism which is deliberately incorporated into most building ventilation systems.

Physical and chemical reactions of pollutants with their surroundings may take several forms: sorption or chemical reactions with building materials and furnishings; chemical reactions with other pollutants; and photodissociation and catalytic reactions (Maki and Woods, 1984). For some pollutants, these reactions may be quite important. Concentrations of nitrogen oxides and sulfur oxides, for example, are heavily influenced by the reactive properties of these compounds. In fact, chemical reactions and sorption can reduce concentrations of nitrogen oxides 48% more quickly than dilution (Maki and Woods, 1984).

1.3 INFLUENCE OF BUILDING DESIGN, OPERATION, AND MAINTENANCE ON INDOOR AIR QUALITY

Indoor air quality problems often result from the inappropriate control of the factors described above with respect to the design, operation, and maintenance of building systems. Common problems include inadequate ventilation, contamination from indoor sources, entrainment of outdoor contaminants into the building, and microbial contamination due to improper design, operation, and maintenance procedures (NIOSH, 1987).

Inadequate Ventilation

Inadequate ventilation is the cause of many indoor air-related health complaints. Specific ventilation deficiencies that produce air quality problems include inadequate outdoor air supply, poor air distribution (and hence poor ventilation effectiveness), inadequate control of temperature and humidity, insufficient maintenance of the ventilation system, inadequate HVAC system capacity, and inadequate exhaust from occupied areas (NIOSH, 1987; Honeywell Incorporated, 1988). Inadequate outdoor air supply and distribution and insufficient control of thermal conditions can result from strategies to control energy consumption.

Numerous case studies illustrate problems caused by ventilation system design and operation deficiencies. Morey (1988) presents two cases in which air quality problems were traced to energy management programs that altered HVAC system operations. Morey and Woods (1987) present examples of insufficient air supply, poor maintenance, and restrictions on heating, ventilation, and air-conditioning (HVAC) operation from energy conservation strategies as originators of air quality problems in buildings.

Contamination from Indoor Sources

Investigations into indoor air quality-related health complaints often identify sources inside the building as the primary cause of the problem. Inside sources responsible for indoor air pollution problems include copy and other office machines, pesticides, cleaning agents, tobacco smoking, and combustion devices. Contamination of the indoor atmosphere can also result from emissions from building materials and products including insulation, pressed wood products, floor and wall coverings, carpeting and adhesives.

The selection and proper installation of building materials and furnishings during design and construction of a building may have important impacts on the building's air quality. This is particularly true of potential pollutant sources such as ceiling tiles, floor and wall coverings, or partitions which have large surface areas capable of offgassing chemical contaminants throughout the occupied space. Special provisions for exhausting contaminants from known source areas such as photocopy rooms, designated smoking areas, or special use facilities such as print shops, are most appropriately made during the design of the building, and properly maintained during its operation.

Re-entrainment and Contamination from Outdoor Sources

Outdoor pollutants or re-entrainment of indoor pollutants sometimes create severe indoor air quality problems because of improperly located air intake vents. For example, these vents, which supply outdoor air into the building, may be located at ground level near a roadway or a parking lot where they allow motor vehicle exhausts to enter the building air supply. Most often, however, these vents are located on the roof; for aesthetic reasons, they are often positioned on the back of the building which may overlook the loading dock or trash storage area, or may be located close to and downwind from the rest room exhaust of the building or an adjacent building.

In each case, unwanted air contaminants may be incorporated into the building air and result in health risk and comfort complaints from the occupants. Thus, while the sources of these indoor air pollution problems are outdoors, the cause of the problem can be traced to faulty design of the HVAC system, and inadequate consideration of the entrainment of pollutants from outdoor sources.

Microbial Contamination

Hypersensitivity pneumonitis and other respiratory diseases often result from microbial contamination of building heating, ventilating, and air conditioning systems, or from contamination of building materials and furnishings. Microbial contamination commonly results from situations of high moisture or humidity. Flooded areas, water-damaged carpeting or furniture, dirty and moist air filters, pools of stagnant water in the drain pans of the HVAC system, or improperly cleaned and maintained humidification systems can result in microbial contamination and building related illnesses. Microbial contamination is most often avoidable through careful building system component design, and through proper maintenance and hygienic practices (Morey, et al. 1984).

Implications

Building systems are designed, constructed, and operated to provide safe, healthy, and comfortable environments for a variety of human activities. The indoor microenvironments created by building systems must provide for the biological, physical, social, and psychological needs of their occupants. Understanding building systems as mechanisms for the control of environmental conditions points to occupant well-being an important criterion by which building adequacy should be judged. Successful building systems produce an environment free from stressors that threaten occupant health, comfort, and productivity.

Building system design and operation can, and regularly do, provide acceptable indoor environments. However, neglect or disregard of the sources of indoor air contaminants, or of the proper design, operation, and maintenance of building system components which influence indoor air quality can create an uncomfortable and unhealthy indoor atmosphere.

1.4 SUMMARY

Some data are available on the U.S. building stock with respect to parameters that are important to indoor air quality. Factors which affect indoor air quality include source emissions from indoor sources, the air exchange rate, outdoor sources and concentrations, and various chemical and physical removal mechanisms. Building system inadequacies commonly identified in investigations of building indoor air quality complaints include inadequate ventilation, contamination from indoor sources, re-entrainment of indoor pollutants, contamination from exterior sources, and microbial problems. Proper design, operation, and maintenance of building system components is important to the achievement and maintenance of good indoor air quality.

REFERENCES

Amols G.R., Howard K.B., Nichols A.K., Guerra T.D. 1988. Residential and Commercial Buildings Data Book. PNL-6454/UC-98. Pacific Northwest Laboratory. Richland WA.

Diamond R.C., Grimsrud D.T. 1983. Manual on Indoor Air Quality. Lawrence Berkeley Laboratory. LBL-17049. University of California, Berkeley, CA.

Honeywell Incorporated. 1988. News Release: Diagnosis of Sick Building Syndrome Points to HVAC Systems as Cause, Cure. Gerry Drewry. Golden Valley, MN.

Maki H.T., Woods J.E. 1984. Dynamic Behavior of Pollutants Generated by Indoor Combustion. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 5:73-78.

Morey, P.R., Hodgson, M.J., Sorenson, W.G., Kullman, G.J., Rhodes, W.W., and Visvesvara, G.S. 1984. Environmental Studies in Moldy Office Buildings: Biological Agents, Sources, and Preventive Measures. Annals of the American Conference of Industrial Hygienists. Vol 10.

Morey P.R. 1988. Microbiological Problems in Office Buildings: Recognition and Remedial Action. pp. 445-454. Proceedings of Energy Technology Conference XV. Government Institutes, Inc. Washington, D.C.

Morey P.R., Woods J.E. 1987. Indoor Air Quality in Health Care Facilities. Occupational Medicine. July-September 1987. pp.547-563.

NIOSH. 1987. Guidance for Indoor Air Quality Investigations. Health Evaluations and Technical Assistance Branch. Cincinnati, OH.

NRC. 1987. Policies and Procedures for the Control of Indoor Air Quality. National Academy Press. Washington, D.C.

Persily, A. 1989. Ventilation Rates in Office Buildings. Paper presented at the ASHRAE Conference IAQ 89. The Human Equation: Health and Comfort. San Diego, CA.

Tucker, W. 1987. Chairman's Summary Session I -- Characterization of Emissions from Combustion Sources: Controlled Studies, in Atmospheric Environment Vol. 21, No. 2.

U.S. Department of Energy (DOE). 1986. Residential Energy Consumption Survey: Housing Characteristics, 1984. Energy Information Administration. DOE/EIA-0314(84). Washington, D.C.

U.S. Department of Energy (DOE). 1985. Nonresidential Buildings Energy Consumption Survey: Characteristics of Commercial Buildings, 1983. Energy Information Administration. DOE/EIA-0246(83). Washington, D.C.

CHAPTER 2 - MEASURING AND MODELING POLLUTANTS AND SOURCES

2.1 POLLUTANTS AND SOURCES

Some information on indoor pollutants, sources, and health effects is known, but extensive investigation is needed to adequately understand the nature and magnitude of the indoor air pollution problem. For example, most pollutant sources do not emit single pollutants, but generate a mixture, which in turn becomes part of the complex mixture that people breathe. The health effects of such a complex mixture cannot be categorically stated, and in most instances, neither the interaction of pollutants with each other, nor the effects on human systems of these pollutants in combination, have been established.

Several hundred specific airborne pollutants have been detected in varying concentrations in indoor environments. These can be grouped into a smaller subset of pollutants and pollutant classes, as shown in Exhibit 2-1.

Exhibit 2-1
Major Indoor Air Pollutants of Concern

Radon and radon daughters
Environmental tobacco smoke (ETS)
Biological contaminants
Volatile organic compounds (VOCs)
Formaldehyde
Polycyclic Aromatic Hydrocarbons (PAHs)
Pesticides
Asbestos
Combustion Gases
Particulate Matter (Particles)

Indoor pollutants can emanate from a broad array of sources that can originate both outside of structures as well as from within a building. Knowledge of sources is critical to the development of effective mitigation strategies (see Chapter 6). Internal sources include, but are not necessarily limited to: combustion appliances, consumer and commercial products, building materials and furnishings, pesticides, HVAC systems, water damaged materials, human occupants and pets, and personal activities such as smoking. External sources include soil, water supplies, and the ambient (outside) air. The relationship between pollutants and their sources may be complex. For example, the concentration of a single pollutant may result from the emissions of several different sources both inside and outside a building.

The magnitude of human exposure to indoor air pollutants is a function of the ability of the pollutants to come in contact with an individual. This depends on the time individuals spend in each indoor micro-environment containing pollutants, and the concentration of each pollutant. Concentrations, in turn, are determined by source emissions and transport processes, both within and between particular microenvironments.

The ambient pollutant concentration in a given microenvironment, and the associated human exposure, can be measured directly or they can be estimated using mathematical models. Developing and/or calibrating these models may require many different types of data, e.g., pollutant sources and their respective emission rates, average and peak pollutant concentrations, air transport processes, and time-activity patterns and demographic characteristics. Assessing indoor air pollutant concentrations can involve as many as three components: source emission testing, air pollution measurements, and modeling.

Source emission testing measures the emission of pollutants from specific sources under laboratory conditions. Source emission testing provides the researcher with detailed information on pollutant emission rates, which allow prediction of the ambient concentrations under specified environmental conditions.

Typical indoor pollutant concentrations can also be measured directly using monitoring instruments. These instruments vary in size from hand-held portable monitors to large, stationary analytical monitors.

Finally, pollutant concentrations can be predicted, rather than measured, using indoor air quality models. Directly monitoring the concentration of the pollutant of concern provides the most accurate information for any particular microenvironment, but technical and financial limitations usually necessitate the additional use of modeling. The models themselves are often calibrated using the results from source emission testing and/or from pollutant concentration measurements.

In this chapter, we discuss the techniques and limitations of source emission testing, field monitoring, and modeling. In addition, we present data from selected studies that measured indoor air pollutant concentrations or exposures.

2.2 SOURCE EMISSION TESTING

The emission of pollutants from indoor sources can be measured directly under laboratory conditions. These tests can provide the researcher with detailed information upon which to estimate or model indoor air pollutant concentrations. In the past, most source emission studies have involved single compound analyses and have focused on three categories of sources: combustion appliances, consumer products, and building materials and furnishings.

The source emission test can be divided into three steps:

(1) A sample of the substance containing the pollutant of concern is prepared in such a way that the sample will provide emission data that approximate, or allow extrapolation to, emissions under normal use;

(2) A test chamber is designed, incorporating environmental test conditions, such as temperature and relative humidity, that are consistent with normal use characteristics; and

(3) The pollutant emissions of concern are measured.

Environmental test chambers vary in size, from small-scale chambers with volumes of less than 1.0 cubic meters (m^3) to large-scale chambers with volumes exceeding 15 m^3. Small chambers are less expensive to construct and operate, and allow greater experimental flexibility with respect to test conditions. Large-scale chambers may simulate actual field characteristics more accurately than small-scale chambers, but are limited by cost, logistical constraints, and problems with leakage.

There are several major laboratories in the U.S. which use test chambers for source emission testing. Oak Ridge National Laboratory in Oak Ridge, Tennessee, has three chambers, with capacities of 0.3, 3.3, and 17 m^3. Although Oak Ridge has the capability to test a broad spectrum of pollutants, the focus of recent work has been on emissions of radon and VOCs, particularly formaldehyde. The three chambers are constructed with different materials to minimize interactions with the tested pollutant: the VOCs are tested in a stainless steel chamber, radon is tested in a plexiglass chamber, and the formaldehyde tests are conducted in a teflon chamber. Broad-spectrum VOC testing has been limited to a few building materials, although a variety of formaldehyde-containing products are tested, including pressed wood and particle board.

EPA's Air and Energy Engineering Research Laboratory (AEERL) at Research Triangle Park, North Carolina has two sizes of emission testing chambers, six with capacities of 0.05 m^3 and two with capacities of 0.16 m^3. Most of AEERL's efforts are concentrated on VOC emissions. AEERL has measured VOC emissions from particleboard, floor adhesives, caulking compounds, moth crystal cakes, wood stains, floor wax, and dry-cleaned clothing. This small chamber testing experience has lead to the development of a draft ASTM guide on source testing. The laboratory has also cooperated with Oak Ridge National Laboratory in its work with petroleum-based solvents. In addition, AEERL sponsors a large kerosene heater testing facility at Yale University, and a three-bedroom test house in North Carolina to simulate normal environmental conditions.

AEERL has also constructed an automated emissions testing facility, which is used to study VOC emissions from common building materials. Air flow rates, temperature, relative humidity, and other environmental data are controlled and recorded by an IBM personal computer.

Lawrence Berkeley Laboratory, in Berkeley, California, measures emissions of radon, products of tobacco combustion, and combustion gases in a 25 m^3 chamber. Volatile and semi-volatile organic chemical emissions from gas appliances and wood stoves are tested in a 20 m^3 chamber. A four liter chamber is used to test emissions from building materials.

Georgia Tech Research Institute, in Atlanta, Georgia, has a test chamber facility with a 25 m^3 test chamber and two smaller 0.2 m^3 chambers. The majority of the research involves VOC source emission testing. Tobacco smoke emissions are measured with a specialized smoking machine that can be loaded into the test chamber. Georgia Tech is currently building a 25 m^3 radon testing chamber.

The Research Triangle Institute in North Carolina uses a small glass test chamber to measure formaldehyde and VOC emissions from building materials and electronic equipment.

Limitations of Source Emission Testing

There are several important limitations to the use of source emission data:

- Most source emission tests are performed with controlled humidity, temperature, ventilation, and air flow characteristics. In indoor environments, these factors vary dramatically over time and even within individual rooms. As a result, actual pollutant concentrations and/or emission rates may be very different from test results if the laboratory conditions do not approximate actual field conditions.

- As textiles, building materials, and indoor combustion sources age, emission rates may vary. Usually source emission testing does not fully account for this phenomenon. Most tests "age" the sample to a specific level and test it over a short period of time.

- Some indoor air pollutants, especially VOCs from building materials and textiles, may be emitted at very low rates. To capture these emissions accurately may require long testing periods and extremely sensitive instruments, all at a considerable cost.

The costs of source emission testing vary widely depending on the specificity of the tests, whether the experimenter has already identified the pollutant(s) of concern, and the size and complexity of the environmental chamber. For example, costs for commercial source emission testing of formaldehyde (or a narrow spectrum of VOCs) from a single, identified source can range from a few hundred dollars for a simple gas chromatography analysis of a sample focusing only on the localized emissions, to tens of thousands of dollars for conducting a broad spectrum VOC analysis using a multi-compartment environmental chamber mock-up of the actual setting. Choosing the extent of the source emission testing will depend on the importance of accuracy and precision in the testing and on cost limitations.

2.3 MODELING

Modeling can be used to estimate pollutant exposure in situations where direct empirical analysis is technically or economically infeasible. In addition, models provide a conceptual framework for designing field experiments and for testing our understanding of exposure. Modeling is also an important policy development tool, for it can be used to estimate present and/or future pollutant exposure and the resulting health risk under various policy or mitigation scenarios. There are four general categories of indoor air pollutant models: source emission models, transport (or indoor air quality) models, statistical models, and population exposure models. In most cases, these models are developed using empirical data obtained from source emission testing and/or field monitoring.

Source Emission Models

Models that predict emissions from indoor pollutant sources are commonly grouped into four categories (Tucker, 1987):

- Combustion -- from unvented and poorly vented appliances and from tobacco smoking;
- Material -- through emanation or evaporation from building materials, furnishings, and consumer products;
- Activity -- direct physical contact with sources (e.g. the use of consumer or commercial products); and

- External -- infiltration of pollutants from outdoor air, soil gas, or releases from indoor water use.

Source emission models are generally developed from controlled emission and transport studies in environmental test chambers or test houses. Exhibit 2-2 lists several of the most recently developed source emission models.

Combustion Sources

A number of researchers have developed emission factors (i.e., pollutant mass released per unit of fuel consumption) to predict emission rates from several indoor combustion sources. However, the age, condition, and use characteristics of indoor combustion appliances, knowledge of which is crucial to creating accurate emission models, are not well documented. The VOC emission rates from indoor combustors are poorly understood and have not yet been modeled. In addition, knowledge of the cause(s), extent, and implications of leakage from vented appliances, which is also important for modeling purposes, is limited (Tucker, 1987). Lastly, emission rates for sidestream smoke from tobacco smoking have been measured for only 100 of the more than 4700 compounds found in sidestream smoke (Sakuma *et al.*, 1984a; Sakuma *et al.*, 1984b).

Material Sources

Most of the source emission modeling for material sources has in the past focused on formaldehyde. The Oak Ridge National Laboratory has developed a general organic compound emissions model, based on a formaldehyde emissions model that used input variables for temperature, relative humidity, formaldehyde transport characteristics, age and decay rate of the sample, and formaldehyde concentration of the room and the particleboard, to predict formaldehyde emissions per unit area of the sample (Hawthorne and Matthews, 1987).

Activity Sources

Activity sources are only qualitatively understood. The emission of pollutants that involve cooking, application of consumer products and pesticides, and the use of appliances and machines have not been analyzed extensively. In one study, however, Girman and Hodgson used a source/exposure model to predict methylene chloride emissions from the use of consumer products such as paint strippers (Girman and Hodgson, 1986).

Exhibit 2-2
Source Emission Models[1]

Source Type	Pollutants	Independent Variables	Reference
Combustion			
Unvented appliances	NO, NO_2, CO	Appliance type, primary aeration level, fuel consumption rate	Relewani *et al.* (1986) Leaderer (1982) Girman *et al.* (1982) Borrazzo *et al.* (1987) Leaderer *et al.* (1987)
Tobacco smoking	ETS, CO, TSP	Density of active smokers	Repace (1986) Girman *et al.* (1982) Sakuma *et al.* (1984a,b)
Material			
Particleboard	Formaldehyde VOCs	Temperature, humidity, formaldehyde in room air, type of material	Matthews *et al.* (1984) Hawthorne *et al.* (1987)
Activity/material			
Consumer products	Solvents	Product composition, type of application	Girman and Hodgson (1986)
External			
Soil gas	Chemically reactive pollutants	Soil gas concentration, indoor-outdoor pressure gradient	Nazaroff and Cass (1986) Nazaroff *et al.* (1984)

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[1] Exhibit 2-2 is based in part from information in EPA 1987a.

External Sources

Several models are available for estimating the effect of external sources on indoor concentrations. For example, Nazaroff and Cass have developed a preliminary version of a general mathematical model that will predict the concentrations of chemically reactive compounds in indoor air. The model accounts for gas-phase photolytic and thermal reactions, and computes the production rates associated with ventilation, filtration, chemical reaction, and direct emission, as well as the removal rates associated with ventilation, chemical reaction, filtration, and adsorption by walls (Nazaroff and Cass, 1986). Models for the prediction of exhaust ventilation on radon entry into homes have been developed by Mowris and Fisk (Mowris and Fisk, 1988; Mowris, 1986)

Indoor Air Quality (Transport) Models

Indoor air quality, or transport, models are used to characterize the movement of air pollutants through defined indoor spaces. These models provide an estimate of the ambient pollutant concentration in a given microenvironment under a variety of user-specified scenarios. Indoor air quality models are particularly important for complex indoor environments, such as office buildings, because the pollutant concentration may vary widely according to the pollutant transport patterns. Important transport models include the NBS model and the AEERL model, which are discussed in this section.

Indoor air pollutant transport patterns are defined by the physical pathways that conduct air from one place to another and the pressure differences that provide the motive forces.[1] Modeling these pathways is a critical component of developing transport models. Important pathways for pollutant transport include penetrations through the building envelope, such as through the windows, doorways, intakes/exhausts, and cracks and seams, that define the leakage patterns of the building, as well as the interior pathways, such as doorways and ventilating/heating ducts. The effects of wind, thermal buoyancy, and pressure differentials caused by mechanical ventilation interact with the leakage configuration and the interior flowpaths to determine each building's transport characteristics.

For single-chamber models, the principal transport process considered is the air exchange across the building envelope. Multi-chamber models require components that address the air exchange for individual airspaces as well as the interior transport among connecting airspaces.

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[1] This section is based on the discussion in EPA 1987a.

NBS Multi-Zone Indoor Air Quality Model

The Indoor Air Quality Model Project, initiated by the Indoor Air Quality and Ventilation Group at the National Bureau of Standards (NBS) (now the National Institute for Science and Technology, or NIST) has developed an indoor air quality model. The model is a generalized simulation program that accounts for pollutant generation, dilution, reaction, and removal as well as infiltration and exfiltration. The model is currently being expanded to include pollutant emissions from and absorption by various materials (EPA, 1988).

AEERL Model

The Air and Energy Engineering Research Laboratory (AEERL) has developed a preliminary version of an indoor air pollutant transport model, which analyzes pollutant migration patterns under user-specified air flow conditions. The model uses a basic pollutant mass balance equation, and can be programmed for a number of indoor pollutant sources, such as cigarettes, kerosene heaters, and unvented stoves, utilizing user-specified source emission rates. The output data provide estimates of the changes in pollutant concentration over time (Sparks, 1988).

Statistical Models

Statistical models allow the researcher to expand the results of field studies to a larger population in the same type of microenvironments as were originally studied. The models use empirical data regarding the distribution of pollutant concentrations, building volumes, air flow patterns, and other user-specified input data to derive estimates of the distribution of pollutant concentrations on a larger scale. All input parameters are assumed to fit a log-normal distribution. The additional use of Monte Carlo computer simulations allows the distributions to be normal, log-normal, empirical, or a variety of other functions (NERDA, and NMPC, 1985).

Population Exposure Models

Population exposure models estimate both indoor and outdoor exposure, and can be used to estimate exposure to a population in diverse settings. Exposure models incorporate three types of data:

- o Input data on the air pollutant concentration and route(s) of exposure experienced by the subject(s);

- The time-activity patterns of the subject(s) during the exposure period; and
- Health or demographic characteristics of the subject(s) that would affect the dose received.

Data on these characteristics are usually developed through a combination of field monitoring, surveying or administering questionnaires, and modeling.

The basis for these exposure models is calculation of total human exposure by summing microenvironmental exposures, which are calculated by multiplying the time spent in a microenvironment times its concentration. Population exposure distributions can then be calculated from microenvironment concentration distributions as well as distributions of time activity patterns which vary among different population subgroups.

Complex population models are dependent on the ability of the researcher to simulate accurately the range of human exposure, activities, and demographic characteristics. Exposure modeling necessitates collecting detailed data or using broad assumptions about these characteristics. The strength of these models is their ability to collapse an enormous amount of data necessary for calculating population exposure profiles.

Population exposure models, like all models, are inherently limited by the tradeoffs between accuracy and cost. For small, relatively homogeneous populations in a limited number of settings, reasonable accuracy is quite feasible. For large, heterogeneous populations in diverse settings, however, accuracy becomes more difficult to attain. Exposure modeling becomes more cost-effective compared to field monitoring as the scale of the project increases and as the required complexity of the model decreases.

There are only a few sophisticated models that can estimate indoor air pollutant exposure, though a number of outdoor air pollutant exposure models have a component for estimating indoor exposure to the outdoor pollutants. Population exposure models include SHAPE, PAQM, and NEM.[2]

SHAPE (Simulation of Human Air Pollution Exposure)

The SHAPE model estimates carbon monoxide exposure to specific individuals by using both background and microenvironmental carbon monoxide concentrations. Data on microenvironmental carbon monoxide concentrations were obtained from extensive field monitoring in the EPA TEAM studies conducted in Denver, Colorado, and Washington, D.C. The model assumes that the background carbon monoxide concentrations of the indoor and outdoor environments are constant over specified time intervals and that the microenvironmental concentrations are additive. The total microenvironmental exposure is derived by summing the individual microenvironment exposures (the product of the pollutant concentrations to which an individual is exposed multiplied by the duration of exposure) experienced during daily activities. The model uses U.S. Census data to estimate demographic information for the involved individuals. The exposure and dosage estimations are based on a human activity model.

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[2] This discussion is based on Pandian (1987).

SHAPE focuses mainly on characterizing the population, exposure, and dosage based on user-specified data on background and microenvironmental carbon monoxide concentrations -- SHAPE does not use dispersion models to estimate carbon monoxide concentrations. Values of demographic variables are determined from probability distributions, which are also user-specified. Moreover, SHAPE only estimates carbon monoxide exposure; it does not assess health risks.

PAQM (Personal Air Quality Model)

PAQM uses an hourly sequence of outdoor pollutant concentrations to compute the indoor concentrations that would be induced within each of several specified building types. The model uses simple mass balance equations and compensates for leakage and mechanical ventilation. PAQM also estimates the exposure of user-specified individuals as they undergo their typical pattern of daily activities, moving between indoor and outdoor environments.

NEM (National Ambient Air Quality Standards Exposure Model)

NEM was developed by EPA to assess total human exposure to pollutants regulated under Section 109 of the Clean Air Act. NEM is a simulation model capable of estimating human exposure to ambient pollutants as people move through time and space as they undertake their usual activities. Indoor exposures are accounted for by adding microenvironment-specific concentrations to that portion of outdoor air that enters the indoor environment. A version of NEM is available (on a PC) that explicitly incorporates air exchange rates and other indoor microenvironmental characteristics.

2.4 FIELD MEASUREMENTS

Field measurement involves two components: (1) collecting a sample of the medium in which the pollutant is typically transported, e.g., air for most indoor pollutants, and (2) analyzing the sample to identify the pollutant(s) and measure the concentration(s). In addition, field monitoring may measure the factors that affect pollutant dispersion, such as humidity, the air exchange rate, the concentration of the pollutant of concern in the surrounding outdoor air, and the pollutant infiltration rate.

Types of Measurement Instruments

Important technical considerations for selecting measurement instruments (monitors) are: sampling mobility, operating characteristics, output characteristics, space and power limitations, noise levels, and analytical requirements.[3] There are three classes of sampling mobility:

- Personal -- the monitor may be worn or hand-held;
- Portable -- the monitor may be hand-carried; and
- Stationary -- the monitor must be operated from a fixed location.

Within each class of sampling mobility, monitors can be classified as either active or passive, depending on whether a power source is required for sample collection. Most active monitors use a pump or blower to collect the sample by absorbing the sample in a liquid medium or onto a solid surface. Active monitors can be used for either gaseous or particulate matter. Passive monitors either diffuse the sample directly into a collection medium or diffuse across a permeable membrane to a collecting medium. Passive monitors are used primarily for measuring gaseous pollutants. Passive monitors can also be used for particulate matter, but because they collect only the particles which fall out of suspension, passive monitors may not accurately estimate the total airborne particulate matter concentration.

Lastly, within each mobility and operating class, the output characteristics fall into two categories:

- Analyzer -- the monitor produces an instantaneous (or nearly instantaneous) signal that corresponds to the pollutant concentration or parameter that is being measured; and
- Collector -- the sample is collected by the unit and subsequently analyzed in the laboratory.

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[3] This discussion is based on Nagda et al., 1987.

Other considerations in selecting the appropriate field monitoring instruments include cost, availability, convenience of use, and desired level of accuracy. Another important factor is whether the pollutant of concern poses the greatest risk from acute or chronic exposure. Toxic pollutants that cause adverse health effects only above a threshold dose should be monitored with an analyzer if the pollutant concentration varies significantly over time.

Pollutant-Specific Measurement Instruments

A wide variety of monitors are available for the major indoor air pollutants. These monitors range in size and complexity from small personal exposure monitors (PEMs) to large, stationary continuous analyzers. Some of these devices can be operated by an untrained individual; others require the services of a trained professional.

For a number of the major pollutants, EPA and/or other organizations have developed protocols that standardize the monitoring procedures. EPA is drafting a Compendium of Methods for the Determination of Air Pollutants in Indoor Air, which when completed will provide regional, state, and local environmental agencies with available protocols for measuring selected indoor air pollutants (EPA, 1987b). For other pollutants, however, generally accepted protocols have not yet been established. In this section, we summarize the measurement instruments that are currently available for the major indoor pollutants, and briefly discuss the generally accepted measurement protocols that address their use in the field.

The number and diversity of the commercially available indoor air pollution measurement instruments precludes a detailed discussion in this report. Nonetheless, in Exhibit 2-3, we have provided a brief summary of the available monitors for the major pollutants; a more detailed summary is included in Exhibit 2-4.

Measurement Protocols

Radon

EPA has developed interim protocols for measuring radon and radon decay products (EPA, 1987c). EPA recommends a two-step strategy, beginning with a screening measurement made under closed-house conditions in an area where radon concentration is expected to be greatest (usually the basement or ground level). Depending on the results of the screening measurement, a second series of follow-up measurements may be required to assess more completely the average concentrations in the living areas of the house.

Exhibit 2-3

Types of Available Measurement Instruments by Pollutant (Nagda et al., 1987)

Pollutant	Type	Personal		Portable		Stationary	
		Active	Passive	Active	Passive	Active	Passive
Radon	Collector						*
	Analyzer	*		*		*	*
Biological aerosols	Collector					*	
	Analyzer						
VOCs	Collector	*		*		*	
	Analyzer						
Formaldehyde	Collector	*	*	*			
	Analyzer					*	
Pesticides/ semi-volatile organics	Collector	*		*		*	
	Analyzer						
Asbestos	Collector	*		*		*	
	Analyzer			*			
Carbon monoxide	Collector						
	Analyzer	*	*	*		*	
Nitrogen dioxide	Collector		*				
	Analyzer		*	*		*	
Particulate Matter	Collector	*		*		*	
	Analyzer		*	*		*	

Exhibit 2-4
Commercially Available Monitors (Nagda, 1987)

POLLUTANT	TYPE	NAME	COMPANY
Radon	Stationary/Passive/Collector	PRM LR-5	AeroVironment, Inc.
	Personal/Active/Analyzer	500 Series, Alpha PRISM System	Alpha Nuclear
	Stationary/Active/Analyzer	RGM-2, Radon Gas Monitor	Eberline Instrument Corporation
	Portable/Active/Analyzer	Working Level Monitor	Eberline Instrument Corporation
	Portable/Active/Analyzer	RDA-200, Radon/Radon Daughter Detector	EDA Instruments, Inc.
	Stationary/Active/Analyzer	RGA-400 Radon Gas Monitor	EDA Instruments, Inc.
	Stationary/Active/Analyzer	WLM-300	EDA Instruments, Inc.
	Stationary/Passive/Collector	PERM, RDT-310	EDA Instruments, Inc.
	Stationary/Active/Analyzer	Radon Daughters Analyzer	Harshaw Chemical Company
	Stationary/Passive/Collector	Track Etch, Radon Detector	Terradex Corporation
Biological Contaminants	Stationary/Active/Collector	#10-800, Viable Sample Kit	Andersen Samplers, Inc.
	Stationary/Active/Collector	#10-850, Two-Stage Microbial Sampler	Andersen Samplers, Inc.
Formaldehyde	Personal/Passive/Collector	PF-1, HCHO Passive Monitor	Air Quality Research, Inc.
	Stationary/Active/Analyzer	TGM 555, Formaldehyde Analyzer	CEA Instruments, Inc.
	Personal/Passive/Collector	PRO-TEK, HCHO Passive Dosimeter, Type C60	Du Pont Applied Technology Instruments
	Personal/Passive/Collector	Formaldehyde Monitor 3750	3M Company
Asbestos	Portable/Active/Analyzer	FAM-1, Fibrous Aerosol Monitor	GCA Corporation
Carbon Monoxide	Portable/Active/Analyzer	2000 Series, CO Analyzer	Energetics Science, Inc.
	Personal/Passive/Analyzer	Model 210, Personal CO Monitor	Energetics Science, Inc.

Exhibit 2-4 (continued)
Commercially Available Monitors (Nagda et al., 1987)

POLLUTANT	TYPE	NAME	COMPANY
Carbon Monoxide	Personal/Active/Analyzer	CO Detector	General Electric Company
	Portable/Active/Analyzer	Models 1140 and 4140 CO Analyzers	Interscan Corporation
	Personal/Passive/Analyzer	Model 5140 CO Analyzer and CX-5 Data Interface	Interscan Corporation
Nitrogen Dioxide	Personal/Passive/Collector	Air Check, NO_2 Home Test Kit	Air Quality Research, Inc. Int.
	Stationary/Active/Analyzer	TGM 55, NO_2 Analyzer	CEA Instruments, Inc.
	Portable/Active/Analyzer	Model 2200, Portable NO_x Analyzer	Columbia Scientific Industries Corporation
	Personal/Passive/Collector	PRO-TEK, NO_2 Passive Dosimeter Type C30	Du Pont Applied Technology Instruments
	Portable/Active/Analyzer	2000 Series, NO_2 Analyzer	Energetics Science, Inc.
	Portable/Active/Analyzer	Models 1150 and 4150, NO_2 Analyzers	Interscan Corporation
	Personal/Passive/Analyzer	Model 5150, NO_2 Analyzer and CX-5 Data Interface	Interscan Corporation
	Personal/Passive/Collector	NO_2 Badge	Micro Filtration Systems
Particulate Matter	Personal/Passive/Analyzer	MINIRAM Aerosol Monitor	GCA Corporation
	Portable/Active/Analyzer	RAM-1, Aerosol Monitor	GCA Corporation
	Personal/Passive/Analyzer	Handheld Aerosol Monitor	PPM, Inc.
	Stationary/Active/Collector	Dichotomous Sampler, Series 241	Sierra-Andersen, Inc.
	Stationary/Active/Collector	Medium Flow Samplers, Series 254	Sierra-Andersen, Inc.
	Personal/Active/Collector	Marple Personal Cascade Impactor	Sierra Instruments, Inc.
	Portable/Active/Analyzer Stationary/Active/Analyzer	Piezo Balance, Model 3500/Model 5000	TSI, Incorporated

If the screening measurement result is less than about four pCi/l, or 0.02 WL, follow-up measurements are probably not required. If the result of the screening measurement is less than about 20 pCi/l, or 0.1 WL, but greater than about 4 pCi/l, or 0.02 WL, EPA recommends that the follow-up measurement consist of an integrated measurement or series of measurements over a 12month period made in the general living areas of the house. These levels are not high enough, however, to warrant immediate action. If the screening measurement result is greater than 20 pCi/l, or 0.1 WL, EPA recommends a more intensive follow-up measurement, because concentrations could cause a significant increase in health risk (EPA, 1987d).

EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program to evaluate the companies offering radon measurement services. Currently, EPA recognizes the use of a number of different types of radon monitors and accompanying measurement protocols. These monitors include alpha-track detectors, charcoal canisters, radon progeny integrating sampling units, continuous radon monitors, continuous working level monitors, and grab sampling devices (see EPA, 1987c; EPA, 1987d).

Environmental Tobacco Smoke

ETS is not typically measured directly. ETS is difficult to measure in indoor microenvironments because it is a complex mixture of constituents, many of which may also arise from other sources. Moreover, it is not practical, or even possible, to measure the full range of ETS constituents, even under laboratory conditions. As a result, most studies of ambient ETS concentrations have instead focused on single constituents of ETS as proxies for total ETS concentration. Proxy constituents have included nicotine, carbon monoxide, particulate matter, aromatic hydrocarbons, and various tobacco-specific chemicals. Monitoring these constituents is described in the relevant sections below.

EPA has developed a protocol for determining the nicotine concentration in indoor air (EPA, 1987b). The method is based on the collection of nicotine by adsorption onto a sorbent resin or acidic surface. Gas chromatography separation with nitrogen-phosphorous detection is employed for analysis.

Biological Contaminants

A common method for sampling biological contaminants is gravity collection, either on culture plates or adhesive slides. As it monitors only the particles that fall out of suspension, this method is not volumetric, and produces a qualitatively biased picture of the air spora.

Volumetric sampling (in which a measured quantity of air is collected and analyzed) includes two general types: 1) viable or cultural methods in which microorganisms are collected and grown under given conditions, and 2) particle methods in which biological particles are visually counted and identified or biochemically or immunologically analyzed.

Cultural methods are useful when information on viability is essential (e.g., for infectious agents), or if the biological organisms must be cultured to be identified (e.g., actinomycetes, bacteria, viruses, and many fungi). The choice of culture media for these samplers is, therefore, critical.

Particle sampling is the method of choice when total biological particles are being assessed or when biological products (toxins, antigens) are being measured. Total fungal spore counts can be conducted using microscopic counting. Newer methods using fluorescent staining may enable counting of bacterial particles as well. Biochemical or immunological analysis of particulate samples is especially useful when known contaminants are to be analyzed. These methods have been used for airborne endotoxins, mycotoxins, and a variety of antigens (e.g., mites and thermophilic actinomycetes). Sampling for particles to be analyzed biochemically or immunologically requires, however, advance knowledge of the compounds of interest. These methods are not useful for surveys of general biological contamination.

Volatile Organic Compounds

Most VOCs can be identified and quantified with gas chromatography and mass spectrometry. In gas chromatography, the sample is vaporized and injected into a column containing a liquid or particulate solid. The column separates the sample into its component compounds according to their affinity for the contents of the column. Mass spectrometry, a more expensive procedure, separates the gaseous sample into its component compounds according to their differing mass and charge.

A significant portion of early monitoring studies for VOCs have utilized Tenax-GC sorbent tubes to collect these compounds. This sorbent suffers from many problems associated with artifact formation, limited capacity for the more volatile compounds (e.g., vinyl chloride and methylene chloride) and for the polar VOCs (e.g., acrylonitrile and ethylene oxide), and variable background contamination. Particular problems occur with toluene, benzene, and, to a lesser extent, styrene, chloroform, and 1,1,1-trichloroethane, all of which are prevalent indoor air pollutants.

Despite the limitations of Tenax, a monitoring system was successfully employed during 1979-85 in the EPA TEAM studies involving 600 residents in four states. Battery operated pumps capable of 12-hour continuous operation were used to sample air through a cartridge containing Tenax. The pump and cartridge were carried in a specially-designed vest worn by the test subjects.

Canister-based collection systems have recently been under development because of the increasing concerns over the reliability of VOC data obtained with Tenax-based monitors. Canister systems use stainless steel canisters which have specially electropolished interiors. This process, known as SUMMA polishing, makes the interior walls of the canister less reactive, which substantially improves the storage capacities for VOCs (up to 30 days).

EPA has designed a protocol for sampling and analysis of VOCs in indoor air (EPA, 1987b). The method collects VOCs in SUMMA canisters for subsequent analysis with gas chromatography.

Portable gas chromatographs are also available for on site analysis. Gas chromatographs may be used to analyze many different pollutants singly or in combination.

Asbestos

Two methods can be used to measure asbestos in air: optical (or light) microscopy, and electron microscopy. Measurements of low-level air pollution from asbestos rely on the much higher resolution obtained from electron microscopy. Higher resolution is needed in this situation for two reasons. First, asbestos constitutes a small fraction (only 0.0001% to 1%) of the particulate matter in a given air sample. Second, the vast majority of fibers in ambient air are too thin to be seen with optical microscopy.

Optical microscopy is the major technique used to determine levels of asbestos in occupational settings, where the size distribution of asbestos fibers is generally larger and the proportion of asbestos fibers to total fibers is higher. Using standard optical microscopy procedures, only fibers longer than 5 um are measured; electron microscopy allows the enumeration and sizing of all asbestos fibers (EPA, 1986).

Samples for electron microscopy are collected on 0.4 um (polycarbonate) or 0.8 um (cellulose ester) filters and counted either directly, after dissolving the filter media, or indirectly, following the ashing of the filter in a furnace. Many earlier analyses by the indirect method resulted in breakdown of the individual fibers, with the loss of information on the distribution of fiber size. For those analyses, air concentrations were reported in terms of mass (e.g., ng/m^3) rather than fiber counts (e.g., fibers/ml) (EPA, 1986).

Because carcinogenic risk estimates for asbestos are based on occupational exposures (in optical microscopy measures of fibers longer than 5 um), exposure data obtained by electron microscopy must be converted to the related optical fiber counts to assess risk. However, the range of conversion factors varies 30-fold in relating optical fiber counts to electron microscopy mass measurements· In addition, direct measurements of electron microscopic fiber counts longer than 5 um cannot be directly converted to optical microscopy counts because a large number of fibers are undetected by optical microscopy (EPA, 1986).

Combustion Gases

The most common method for continuous carbon monoxide monitoring in indoor air is based on non-dispersive infrared (NDIR) spectroscopic detection. Although sensitive enough for typical indoor air concentrations, NDIR instruments are too bulky and complex for personal exposure monitoring. To address this need, carbon monoxide personal monitors have been developed, most of which are based on electrochemical detection; that is, they employ a liquid or solid electrolyte in which carbon monoxide is converted to CO_2, thereby generating an electrical signal. The signal is proportional to the quantity of carbon monoxide present in the gas stream, and the continuous electrical signal is either recorded internally or displayed on a digital readout system.

The most promising electrochemical personal exposure monitor was developed by the General Electric Company and was used in the EPA TEAM pilot studies in Denver, Colorado in 1982-83. While this active monitor functioned well, it required daily servicing. For a large survey, use of this or similar active monitors would incur prohibitive costs. A sensitive and reliable passive carbon monoxide monitor has not yet been developed.

Two main passive devices are available for measuring exposure to NO_2: the Palmes tube and the Yanagisawa badge. These devices rely on NO_2 diffusion to and reaction with triethanolamine, forming a stable complex for subsequent analysis by spectrophotometry. Considerable progress has been made in the development of portable real-time NO_2 monitors, based on the chemiluminescent (light-producing) reaction between NO_2 and luminol. Recent research and development sponsored by EPA has led to the commercialization of a small, light-weight monitor. A prototype electrochemical sensor system was recently developed by a private company with EPA support. Two active NO_2 monitors are currently being tested for indoor sampling application.

Particulate Matter

Particle samplers for outdoor air monitoring are large, noisy, and cumbersome to use. Some continuous particle monitors are available (i.e., the piezo balance), but are large and complex for indoor monitoring. Generally, particle samplers have poor sensitivities and/or unknown accuracy at the low particle concentrations found in non-occupational settings. The newly developed 4 and 10 lpm samplers have been documented to be reliable when compared with standard ambient monitoring equipment.

Limitations of Measurement Methods

Recent scientific advances have considerably increased the accuracy of sampling and analytical methods. Accurately measuring indoor air pollutant levels, however, remains limited by a number of factors:

- The concentrations of some indoor air pollutants are often too low to generate accurate and reproducible results, given current monitoring technology. Although sampling techniques are being developed quickly in response to growing public concern over indoor air pollution, standard technical measurement methods are needed for several of the major pollutants to ensure consistency.

- Although sampling and analytical methods for biological aerosols are available, insufficient knowledge of background levels makes interpreting the results difficult (Knoppel, 1987).

- The concentration of many indoor pollutants varies significantly within and between rooms. This complicates the association between measured concentrations and actual human exposure. The use of personal exposure monitors circumvents this problem by directly measuring personal exposure.

- Other chemical compounds may interfere with the measurement process. For example, nitrogen oxides interfere with the measurement of carbon monoxide, and ETS interferes with the measurement of nitrogen oxides (Wadden and Scheff, 1983).

- The costs of large scale field monitoring studies may be prohibitive, particularly when they involve the development and administration of surveys, and sophisticated research measurements.

2.5 INTEGRATION OF MEASURING AND MODELING TECHNIQUES TO PREDICT EXPOSURE

As noted above, in most cases, estimating or predicting exposure to indoor air pollutants is an integrated procedure. Most sophisticated indoor air pollutant models use the data from source emission testing and field monitoring to calibrate and verify the components of the model being developed. Although indoor air quality modeling is still an emerging field, it can provide useful estimates of indoor air pollutant concentrations in specific settings and under specified conditions, and is useful in predicting the effectiveness of various policy or mitigation alternatives. Field monitoring is needed to collect actual, site specific concentrations or concentration distributions.

2.6 MEASURED INDOOR AIR POLLUTANT CONCENTRATIONS AND EXPOSURES

Many studies in which indoor air pollutants were measured have been conducted. The results of these studies provide valuable insights into the extent of the potential health risks posed by exposure to indoor air pollutants. There are, however, many gaps in the current knowledge regarding the scope and magnitude of the average and peak exposures to indoor air pollutants. In this section, we summarize some of the efforts to characterize indoor air pollution concentrations and/or measure actual personal exposure to these pollutants.

Summary of Reported Concentrations in Indoor Environments

Many researchers have characterized indoor air quality for a wide variety of pollutants (Exhibit 2-5). Most of these efforts have been directed toward determining average or typical pollutant levels. However many studies have focused on measuring pollutant levels in "sick buildings" or other microenvironments with elevated concentrations of certain pollutants. Comparison and interpretation of different studies is made difficult by the disparity of methodologies used, and the limited reporting of quality assurance procedures, particularly in some of the earlier studies. In addition, there is great variability in indoor air pollutant concentrations, both within and across microenvironments, depending on a multitude of factors, as described in previous chapters.

The studies reported here are not meant to be representative of typical indoor concentrations, or the range of concentrations. Providing a representative data base for indoor air pollutant concentrations is beyond the scope of this report. The studies do demonstrate, however, that a wide spectrum of indoor air pollutants are present in most indoor environments.

Exhibit 2-5
Summary of Reported Indoor Air Pollutant Concentrations

	Measured Concentration			Type of	
Pollutant	Minimum	Maximum	Mean	Building	Reference
Radon			0.8 pCi/l	Residences	EPA (1987d)
	0.5 pCi/l	2000 pCi/l		Residences	EPA (1987b)
	0.14 pCi/l	4.11 pCi/l	--	New pub. bldgs.	Sheldon et al. (1988)
	0.3 pCi/l	1.68 pCi/l	--	Old pub. bldgs.	Sheldon et al. (1988)
	--	--	1.7-2.4 pCi/l	3 office bldgs	Bayer & Black (1988a)
ETS (as RSP)	--	--	28 ug/m^3 (1)	Residences	NRC (1986b)
	--	--	74 ug/m^3 (2)	Residences	NRC (1986b)
	--	--	32 ug/m^3 (3)	Residences	DHHS (1986)
	--	--	50 ug/m^3 (4)	Residences	DHHS (1986)
(as nicotine)	--	--	0.7-3.2 ppb	3 office bldgs	Bayer & Black (1988a)
Biological Contaminants	--	564-5360 CFU/m^3 (5)		3 office bldgs	Bayer & Black (1988a)
VOCs (see also Exhibits 2-6, 2-7, and 2-8)					
Formaldehyde	--	131-319 ug/m^3	78-144 ug/m^3	Residences	Hawthorne et al. (1984)
	ND	192 ppb	--	New pub. bldgs.	Sheldon et al. (1987)
	ND	103 ppb	--	Old pub. bldgs	Sheldon et al. (1987)
	--	--	25-39 ppb	3 office bldgs	Bayer & Black (1988a)
Benzene	--	120 ug/m^3	20 ug/m^3	Various	Wallace et al. (1983)
Carbon tetrachloride	--	14 ug/m^3	2.5 ug/m^3	Various	Wallace et al. (1983)
Trichloroethylene	--	47 ug/m^3	3.6 ug/m^3	Various	Wallace et al. (1983)
Tetrachloroethylene	--	250 ug/m^3	10 ug/m^3	Various	Wallace et al. (1983)
Chloroform	--	200 ug/m^3	8 ug/m^3	Various	Wallace et al. (1983)
Dichlorobenzenes	--	1200 ug/m^3	41 ug/m^3	Various	Wallace et al. (1983)

ND = not detected; CFU = colony forming units

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[1] 73 residences without smokers

[2] 28 residences with smokers

[3] Nonsmokers not exposed to ETS

[4] Nonsmokers exposed to ETS

[5] Summation of mesophilic bacteria, fungi, and thermophilic bacteria

Exhibit 2-5 (cont.)
Summary of Reported Indoor Air Pollutant Concentrations

Pollutant	Measured Concentration Minimum	 Maximum	 Mean	Type of Building	Reference
Ethylbenzene	--	320 ug/m^3	13 ug/m^3	Various	Wallace et al. (1983)
	--	12 ug/m^3	4.4 ug/m^3	Residences	Hawthorne et al. (1984)
Xylenes					
o-Xylene	--	49 ug/m^3	7.8 ug/m^3	Various	Wallace et al. (1983)
m,p-Xylene	--	120 ug/m^3	21 ug/m^3	Various	Wallace et al. (1983)
		54-697 ug/m^3	17-44 ug/m^3	Residences	Hawthorne et al. (1984)
Toluene	--	58-655 ug/m^3	27-62 ug/m^3	Residences	Hawthorne et al. (1984)
Pesticides					
Chlorpyrifos	0.014 ug/m^3	15 ug/m^3	2.4 ug/m^3	Residences	Lewis et al. (1986)
Diazinon	ND	8.8 ug/m^3	1.4 ug/m^3	Residences	Lewis et al. (1986)
Chlordane	ND	1.7 ug/m^3	0.51 ug/m^3	Residences	Lewis et al. (1986)
Propoxur	ND	0.66 ug/m^3	0.23 ug/m^3	Residences	Lewis et al. (1986)
Heptachlor	ND	0.31 ug/m^3	0.89 ug/m^3	Residences	Lewis et al. (1986)
Asbestos	--	--	--	--	--
Combustion gases					
Carbon monoxide	0.89 ppm	3.1 ppm	--	Old pub. bldgs	Sheldon et al. (1988)
	--	--	<2 ppb	3 office bldgs	Bayer & Black (1988a)
Nitrogen dioxide	10 ppb	49 ppb	--	Elderly home	Sheldon et al. (1988)
	2 ppb	70 ppb	--	Older pub. bldgs	Sheldon et al. (1988)
Particulate matter					
	trace (IP)	53.3 ug/m^3 (IP)	--	New pub. bldgs	Sheldon et al. (1988)
	trace (RP)	52.8 ug/m^3 (RP)	--	New pub. bldgs	Sheldon et al. (1988)
	4.1 ug/m^3 (IP)	26.7 ug/m^3 (IP)	--	Old pub. bldgs	Sheldon et al. (1988)
	3.5 ug/m^3 (RP)	55.5 ug/m^3 (RP)	--	Old pub. bldgs	Sheldon et al. (1988)
	--	--	0.04-.57 mg/m^3	3 office bldgs	Bayer & Black (1988a)
	ND	74 ug/m^3 (IP)	--	Various	Sheldon et al. (1988)
	ND	100 ug/m^3 (RP)	--	Various	Sheldon et al. (1988)
	--	--	24.4 ug/m^3 (6)	Residences	Spengler & Ferris (1985)
	--	--	36.5 ug/m^3 (7)	Residences	Spengler & Ferris (1985)
	--	--	70.4 ug/m^3 (8)	Residences	Spengler & Ferris (1985)

ND = not detected; IP = inhalable (coarse) particles; RP = respirable (fine) particles.

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[6] RP concentrations in 55 homes, no smokers

[7] RP concentrations in 55 homes, 1 smoker

[8] RP concentrations in 55 homes, 2 smokers

Monitoring in and Around Public Access Buildings

In a project for EPA's Environmental Monitoring and Support Laboratory in Research Triangle Park, NC, Sheldon et al. monitored the air in and around a variety of public buildings, and measured the emission rates of chemicals from building materials used in one of the same buildings (Sheldon et al., 1987). The researchers compared the emission testing data with the field monitoring data and reported activities in the buildings in order to relate potential sources with measured pollutant levels.

The pollutants in the study included VOCs, nitrosamines, pesticides/PCBs, particles, polynuclear aromatic hydrocarbons, metals, formaldehyde, radon, carbon monoxide, nitrogen dioxide, and asbestos. Six buildings were sampled: a new hospital, office, and nursing home, and an older office, office/school, and nursing home. The new buildings were monitored immediately (one to four weeks) after construction and again one or two times after occupancy. Each building was sampled at three indoor locations and one outdoor location. Twelve hour air exchange rate measures were made in parallel with sampling for target chemicals.

The sampling results are summarized in Exhibit 2-6. Radon levels at all buildings were generally low (<2.0 pCi/l). Only one sample, collected at the new office, showed an elevated level of 4.11 pCi/l.

The VOC data show several interesting trends:

- The new buildings showed very high levels of VOCs immediately after construction; these levels decreased dramatically during subsequent field monitoring trips.

- The major indoor air pollutants in the new buildings monitored immediately after construction were the aliphatic hydrocarbons. Levels of the aliphatic hydrocarbons in the older buildings were quite low, while the mean outdoor concentrations were below the quantifiable limit in all cases.

- Although the aromatic hydrocarbons were ubiquitous, they were also found in the highest concentrations in the new buildings immediately after construction.

- Mean indoor concentrations for chlorinated hydrocarbons were highest for the existing office building, presumably from the use of solvent-based cleaning products.

Exhibit 2-6

Indoor Air Quality Monitoring Data (Sheldon *et al.*, 1987)

Building	Pollutant	Min	Max	Mean	Std Dev
New Public Buildings					
	Radon	0.14 pCi/l	4.11 pCi/l	--	--
	ETS	NT			
	Biological Contaminants	NT			
	Total VOCs	--	--	21-1100 ug/m^3	--
	Aromatic hydrocarbons		--	11-270 ug/m^3	--
	Aliphatic hydrocarbons		--	4.7-810 ug/m^3	--
	Chlorinated hydrocarbons		--	3.9-56 ug/m^3	--
	Oxygenated hydrocarbons		--	ND-9.6 ug/m^3	--
	Formaldehyde	ND	192 ppb	--	--
	Pesticides	ND	20 ng/m^3	--	--
	Asbestos	ND	ND		
	Carbon monoxide	NT			
	Nitrogen dioxide	NT			
	Particles	trace (IP)	53.3 ug/m^3 (IP)	--	--
		trace (RP)	52.8 ug/m^3 (RP)	--	--
Older Public Buildings					
	Radon	0.3 pCi/l	1.68 pCi/l	--	--
	ETS	NT			
	Biological Contaminants	NT			
	Total VOCs	--	--	18-130 ug/m^3	--
	Aromatic hydrocarbons		--	12-74 ug/m^3	--
	Aliphatic hydrocarbons		--	1.9-18 ug/m^3	-
	Chlorinated hydrocarbons		--	4.1-46 ug/m^3	--
	Oxygenated hydrocarbons		--	ND-4.3 ug/m^3	--
	Formaldehyde	ND	103 ppb	--	--
	Pesticides	ND	43 ng/m^3	--	--
	Asbestos	ND	ND		
	Carbon monoxide	0.89 ppm	3.1 ppm	--	--
	Nitrogen dioxide	2 ppb	70 ppb	--	--
	Particles	4.1 ug/m^3 (IP)	26.7 ug/m^3 (IP)	--	--
		9.9 ug/m^3 (RP)	55.5 ug/m^3 (RP)	--	--

NT = not tested; ND = not detected; IP = inhalable (coarse) particles; RP = respirable (fine) particles.

Formaldehyde levels were highest in the new buildings. The researchers concluded that the formaldehyde (and the a-pinene) had outgassed from furniture that had been recently moved into the buildings. The pesticide concentrations were low (23 ng/m^3 and below), because most of the pesticides targeted for monitoring had not been applied in the buildings.

In areas where there was no smoking, indoor particle concentrations were generally lower than outdoor concentrations for both inhalable (course) and respirable (fine) particulates. This is not surprising since all buildings had mechanical Carbon monoxide levels ranged from 0.89 to 3.1 ppm; nitrogen dioxide levels ranged from 2 to 63 ppb. There were no general trends in the combustion gas data.

Air exchange rates were generally within the range of 0.3 to 0.6 air changes per hour. Air exchange rates at night were generally less than during the day.

Indoor Air Quality Evaluations of Three Office Buildings

In a project supported by ASHRAE and EPA, Bayer and Black conducted monitoring analyses at three office buildings, focusing on three parameters: (1) ventilation effectiveness, (2) human health and comfort factors, and (3) air pollutant concentrations (Bayer and Black, 1988a). The first building was a 6000 square foot three story building approximately one year old. It had been designed to incorporate special construction and furnishing features in order to optimize indoor air quality and to minimize the levels of indoor air pollutants. The second building was used as the control building. It was a 12,000 square foot three story building of approximately the same age as building 1. However, it had been constructed without the special efforts used in building 1 to minimize the level of indoor air pollutants. The third building had been associated with adverse health symptoms. It was a 57,800 square foot three story building approximately six years old.

Bayer and Black evaluated air quality by assessing personal health and comfort, ventilation effectiveness, environmental conditions, i.e., temperature and humidity, and concentrations of ten pollutants. The pollutants were formaldehyde and other VOCs, nicotine, particles, nitrogen dioxide, carbon monoxide, carbon dioxide, biological contaminants, trace metals, and radon. The results of the pollutant analyses are presented in Exhibit 2-7.

Exhibit 2-7
Indoor Air Quality Monitoring Data (Bayer and Black, 1988a,b)

Building	Pollutant	Min	Max	Mean	Std Dev
Building 1					
	Radon	--	--	2.4 pCi/l	1 pCi/l
	ETS (as nicotine)	--	--	0.07 ppb	1 ppb
	Biological Contaminants	--	5360 CFU (total)		--
	Total VOCs	--	--	237 ug/m^3	182 ug/m^3
	Formaldehyde	--	--	25 ppm	5 ppm
	1,1,1-Trichloro-ethane	--	--	31.0 ug/m^3	--
	Benzene	--	--	14.9 ug/m^3	--
	Ethylbenzene	--	--	1.16 ug/m^3	--
	o-Xylene	--	--	3.66 ug/m^3	--
	Toluene	--	--	7.84 ug/m^3	--
	3-Methylpentane	--	--	1.42 ug/m^3	--
	Hexane	--	--	4.70 ug/m^3	--
	1,2,3-Trimethyl-benzene	--	--	0.52 ug/m^3	--
	Pesticides	NT			
	Asbestos	NT			
	Carbon monoxide	--	--	<2 PPM	--
	Nitrogen dioxide	--	--	4 ppb	3 ppb
	Particles	--	--	0.04 mg/m^3	0.02 mg/m^3
Building 2					
	Radon	--	--	2.0 pCi/l	1 pCi/l
	ETS (as nicotine)	--	--	0.34 ppb	1 ppb
	Biological Contaminants	--	1580 CFU (total)		--
	Total VOCs			401 ug/m^3	653 ug/m^3
	Formaldehyde	--	--	30 ppm	9 ppm
	1,1,1-Trichloro-ethane	--	--	14.8 ug/m^3	--
	Benzene	--	--	12.9 ug/m^3	--
	Ethylbenzene	--	--	4.60 ug/m^3	--
	o-Xylene	--	--	10.6 ug/m^3	--
	Toluene	--	--	48.7 ug/m^3	--
	3-Methylpentane	--	--	19.2 ug/m^3	--
	Hexane	--	--	68.7 ug/m^3	--
	1,2,3-Trimethyl-benzene	--	--	0.02 ug/m^3	--
	Pesticides	NT			
	Asbestos	NT			
	Carbon monoxide	--	--	<2 PPM	--
	Nitrogen dioxide	--	--	12 ppb	4.8 ppb
	Particles	--	--	0.57 mg/m^3	1.3 mg/m^3

NT = not tested; CFU = colony forming units

Exhibit 2-7 (cont.)
Indoor Air Quality Monitoring Data (Beyer and Black, 1988a)

Building	Pollutant	Min	Max	Mean	Std Dev
Building 3					
	Radon	--	--	1.7 pCi/l	0.4 pCi/l
	ETS (as nicotine)	--	--	3.2 ppb	2 ppb
	Biological Contaminants	--	564 CFU (total)		--
	Total VOCs	--	--	1090 ug/m^3	728 ug/m^3
	Formaldehyde	--	--	39 ppm	4 ppm
	1,1,1-Trichloro-ethane	--	--	214 ug/m^3	--
	Benzene	--	--	43.2 ug/m^3	--
	Ethylbenzene	--	--	17.2 ug/m^3	--
	o-Xylene	--	--	16.8 ug/m^3	--
	Toluene	--	--	98.7 ug/m^3	--
	3-Methylpentane	--	--	37.6 ug/m^3	--
	Hexane	--	--	68.1 ug/m^3	--
	1,2,3-Trimethyl-benzene	--	--	0.02 ug/m^3	--
	Pesticides	NT			
	Asbestos	NT			
	Carbon monoxide	--	--	<2 PPM	--
	Nitrogen dioxide	--	--	8 ppb	3 ppb
	Particles	--	--	0.12 mg/m^3	0.16 g/m^3

NT = not tested; CFU = colony forming units

Bayer and Black formulated a number of conclusions regarding the indoor air quality at the three buildings (Bayer and Black, 1988b):

- The pollutant concentrations of nicotine, particles, formaldehyde, NO_2, and total VOCs were lowest in Building 1, which had been constructed to optimize indoor air quality. The low nicotine and particle concentrations were attributed to the absence of smoking in the building. The use of electricity-generated heat, and natural materials for construction materials, furnishings, and upholstery in this building contributed to the low NO_2 levels (natural materials are more efficient sinks for NO_2). The measures taken to reduce or eliminate the use of formaldehyde in the building did not significantly reduce formaldehyde levels relative to the other two buildings. The high total levels of biological contaminants were probably caused by a flood that had occurred on the first floor prior to the field monitoring period.

- In Building 2, the control building, VOC, trace metal, and particle concentrations were highest in the graphic arts area. The elevated NO_2 levels were linked to the use of a gas-fired heating system.

- Elevated VOC levels were the most significant finding in Building 3, which had been the subject of occupant complaints.

Total Exposure Assessment Methodology Studies (TEAM)

Measuring indoor air pollutant concentrations provides important data on the extent of contamination in major microenvironments. The potential impact of pollutants on human health, however, also depends on the amount of time individuals spend in the presence of these pollutants. Accordingly, actual human exposure to these pollutants has become the focus of recent research efforts. A number of studies have estimated actual pollutant exposure through a combination of field monitoring and exposure assessment. The most extensive of these research efforts have been the EPA Total Exposure Assessment Methodology (TEAM) studies.

In 1979, EPA began the Total Exposure Assessment Methodology (TEAM) studies to directly measure human exposure to pollutants, largely focusing on VOCs (Wallace, 1987). This program developed methods to measure individual total exposure and the resulting body burdens of toxic and carcinogenic chemicals. The main TEAM study involved 600 participants from New Jersey, North Carolina, North Dakota, and California. These participants were chosen to represent a total population of 700,000 residents. Each participant carried a personal air sampler throughout a normal 24-hour day, collecting a 12-hour daytime sample and a 12-hour overnight sample. Identical samplers set up near some participants' homes measured the outdoor ambient air. Each participant also collected two drinking water samples. At the end of the 24 hours, each participant contributed a sample of exhaled breath.

All air, water, and breath samples were analyzed for 20 target VOCs. Eleven of the target chemicals were prevalent in the personal air samples, and measured personal air concentrations were generally significantly higher than outdoor concentrations. The results for the New Jersey and California studies are summarized in Exhibit 2-8. In New Jersey, average personal air VOC concentrations for the 11 compounds ranged from 338 ug/m^3 during Fall 1981 to 200 ug/m^3 in Summer 1982. In California, average personal air VOC concentrations for 19 compounds ranged from 240 ug/m^3 during February 1984 (Los Angeles) to 72 ug/m^3 in June 1984 (Contra Costa). EPA concluded that likely residential sources of the VOCs were furniture, solvents, paints, drapes, and construction materials. The TEAM study had several important findings (Wallace, 1987):

- Mean personal air exposures to essentially every one of the 11 prevalent target VOCs were greater than mean outdoor concentrations at seven of eight locations/ monitoring periods.

- The breath levels correlated significantly with personal air exposures to nearly all chemicals, but did not correlate with outdoor air levels.

- A number of specific sources were identified, including smoking (benzene, xylenes, ethylbenzene, and styrene in breath), passive smoking (benzene, xylenes, ethylbenzene, and styrene in indoor air), visiting dry cleaners (tetrachloroethylene in breath), and pumping gas or exposure to automobile exhaust (benzene in breath).

- Other sources were hypothesized, including use of hot water in the home (chloroform in indoor air) and room air fresheners, toilet bowl deodorizers, or moth crystals (p-dichlorobenzene in indoor air.

- For all chemicals, except the trihalomethanes, inhalation provided greater than 99 percent of the exposure.

Exhibit 2-8

Weighted Estimates of Air and Breath Concentrations of 11 Prevalent Compounds for 130,000 Elizabeth-Bayonne Residents (Fall 1981); 110,000 Residents (Summer 1982); and 49,000 Residents (Winter 1983)

(Source: Wallace 1987)

	Season I (Fall)			Season II (Summer)			Season III (Winter)		
Compound	Personal Air (N=340)	Outdoor Air (86)	Breath (300)	Personal Air (150)	Outdoor Air (60)	Breath (110)	Personal Air (49)	Outdoor Air (9)	Breath (49)
1,1,1-Trichloroethane	94[a]	7.0[a]	15[b]	67	12	15	45	1.7	4.0
m,p-Dichlorobenzene	45	1.7	8.1	50	1.3	6.3	71	1.2	6.2
m,p-Xylene	52	11	9.0	37	10	10	36	9.4	4.7
Tetrachloroethylene	45	6.0	13	11	6.2	10	28	4.2	11
Benzene	28	9.1	19	NC[c]	NC	NC	NC	NC	NC
Ethylbenzene	19	4.0	4.6	9.2	3.2	4.7	12	3.8	2.1
o-Xylene	16	4.0	3.4	12	3.6	5.4	13	3.6	1.6
Trichloroethylene	13	2.2	1.8	6.3	7.8	5.9	4.6	0.4	0.6
Chloroform	8.0	1.4	3.1	4.3	13	6.3	4.0	0.3	0.3
Styrene	8.9	0.9	1.2	2.1	0.7	1.6	2.4	0.7	0.7
Carbon tetrachloride	9.3	1.1	1.3	1.0	1.0	0.4	ND[d]	ND	ND
Total (11 compounds)	338	38	80	200	59	66	216	25	31

a. Average of arithmetic means of day and night 12-hour samples (ug/m^3)

b. Arithmetic mean

c. Not calculated - high background contamination

d. Not detected in most samples

Weighted Estimates of Air and Breath Concentrations of Nineteen Prevalent Compounds for 360,000 Los Angeles Residents (February 1984); 330,000 Los Angeles Residents (May 1984); and 91,000 Contra Costa Residents (June 1984)

	LA1 (Feb)			LA2 (May)			CC (June)		
Compound	Personal Air (N=110)	Outdoor Air (24)	Breath (110)	Personal Air (50)	Outdoor Air (23)	Breath (50)	Personal Air (76)	Outdoor Air (10)	Breath (76)
1,1,1-Trichloroethane	96[a]	34	39	44	5.9	23	16	2.8	16[b]
m,p-Xylene	28	24	3.5	24	9.4	2.8	11	2.2	2.5
m,p-Dichlorobenzene	18	2.2	5.0	12	0.8	2.9	5.5	0.3	3.7
Benzene	18	16	8.0	9.2	3.6	8.8	7.5	1.9	7.0
Tetrachloroethylene	16	10	12	15	2.0	9.1	5.6	0.6	8.6[b]
o-Xylene	13	11	1.0	7.2	2.7	0.7	4.4	0.7	0.6
Ethylbenzene	11	9.7	1.5	7.4	3.0	1.1	3.7	0.9	1.2
Trichloroethylene	7.8	0.8	1.6	6.4	0.1	1.0	3.8	0.1	0.6
n-Octane	5.8	3.9	1.0	4.3	0.7	1.2	2.3	0.5	0.6
n-Decane	5.8	3.0	0.8	3.5	0.7	0.5	2.0	3.8	1.3
n-Undecane	5.2	2.2	0.6	4.2	1.0	0.7	2.7	0.4	1.2
n-Dodecane	2.5	0.7	0.2	2.1	0.7	0.4	2.1	0.2	0.4
a-Pinene	4.1	0.8	1.5	6.5	0.5	1.7	2.1	0.1	1.3
Styrene	3.6	3.8	0.9	1.8	--	--	1.0	0.4	0.7
Chloroform	1.9	0.7	0.6	1.1	0.3	0.8	0.6	0.3	0.4
Carbon tetrachloride	1.0	0.6	0.2	0.8	0.7	0.2	1.3	0.4	0.2
1,2-Dichloroethane	0.5	0.2	0.1	0.1	0.06	0.05	0.1	0.05	0.04
p-Dioxane	0.5	0.4	0.2	1.8	0.2	0.05	0.2	0.1	0.2
o-Dichlorobenzene	0.4	0.2	0.1	0.3	0.1	0.04	0.6	0.07	0.08
Total (19 compounds)	240	120	80	150	33	56	72	16	44

a. Average of arithmetic means of day and night 12-hour samples (ug/m^3)

b. One very high value

2.7 SUMMARY

Several hundred specific airborne pollutants have been detected in varying concentrations in indoor environments. These are grouped into a convenient subset of pollutants and pollutant classes. Indoor pollutants emanate from a broad array of sources that can originate both outside structures as well as from within a building.

Ambient pollutant concentrations in a given microenvironment, and the associated human exposure, can be measured directly or they can be estimated using mathematical models. These techniques include source emission testing, modeling, and field measurements. Various source emission models, indoor air quality models, and human exposure models have been developed. Measurement protocols are needed to accurately determine indoor concentrations. Such protocols are specific to individual pollutants or pollutant classes, and to measurement objectives.

Estimation and prediction of human exposure to indoor contaminants involves the integration of measurement and modeling procedures. Most models use the data from source emission testing and field measurements to calibrate and verify components of the model. Models can provide estimates of exposure to specified conditions and are therefore useful in evaluating alternative policy or mitigation options. Field monitoring is necessary to collect site specific concentrations and concentration distributions.

REFERENCES

Bayer, C.W. and Black, M.S. 1988a. Indoor Air Quality Evaluations of Three Office Buildings: Two of Conventional Construction Designs and One of a Special Design to Reduce Indoor Air Contaminants. Georgia Institute of Technology, Athens, Georgia.

Bayer, C.W, and Black, M.S. 1988b. Indoor Air Quality Evaluations of Three Office Buildings. Engineering Solutions to Indoor Air Problems, ASHRAE.

Borrazzo, J.E., Osborn, J.F., Fortmann, R.C., Keefer, R.L., and Davidson, C.I. 1987. Modeling and Monitoring of CO, NO and NO_2 in a Modern Townhouse. Atmospheric Environment, Vol. 21, No. 2.

Department of Health and Human Services (DHHS). 1986. The Health Consequences of Involuntary Smoking -- A Report of the Surgeon General.

Environmental Protection Agency (EPA). 1986. Airborne Asbestos Health Assessment Update, EPA/600/8-84/003F, Office of Research and Development.

Environmental Protection Agency (EPA). 1987a. Draft Report: Indoor Air Pollution -- The Magnitude and Anatomy of Problems and Solutions, A Scoping Study.

Environmental Protection Agency (EPA). 1987b. Compendium of Methods for the Determination of Air Pollutants in Indoor Air. Environmental Monitoring Systems Laboratory.

Environmental Protection Agency (EPA). 1987c. Interim Protocols for Screening and Follow-up Radon and Radon Decay Product Measurements. EPA 520/1-86-014, Office of Radiation Programs.

Environmental Protection Agency (EPA). 1987d. Radon Reference Manual. EPA 520/1-87-20, Office of Radiation Programs.

Environmental Protection Agency (EPA). 1987e. EPA Indoor Air Quality Implementation Plan -- Appendix A: Preliminary Indoor Air Pollution Information Assessment. Office of Health and Environmental Assessment.

Environmental Protection Agency (EPA). 1988. Current Federal Indoor Air Quality Activities. Office of Air and Radiation.

Girman, J.R., Apte, M.G., Traynor, G.W., Allen, J.R., and Hollowell, C.D.. 1982. Pollutant Emission Rates from Indoor Combustion Appliances and Sidestream Cigarette Smoke. Environment International, Vol. 8:213-221.

Girman, J.R. and Hodgson, A.T. 1986. Source Characterization and Personal Exposure to Methylene Chloride from Consumer Products. Presented at the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, MN.

Hawthorne, A. and Matthews, T. 1987. Models for Estimating Organic Emissions from Building Materials: Formaldehyde Example. Atmospheric Environment, Vol. 21, No. 2.

Hawthorne, Alan, et al. 1984. An Indoor Air Quality Study of Forty East Tennessee Home. Oak National Laboratory.

Knoppel, H. 1987. Sampling and Analysis: Chamber and Field Studies. Atmospheric Environment, Vol. 21, No. 2.

Leaderer, B.P. 1984. Air Pollutant Emissions from Kerosene Space Heaters. Science, Vol. 218.

Leaderer, B.P., Zagraniski, R.T., Berwick, M., and Stolwijk, J.A. 1987. Predicting NO_2 Levels in Residences based upon Sources and Source Use: A Multivariate Model. Atmospheric Environment, Vol. 21, No. 2.

Lewis, R.G., and Bond, A.E. 1987. Non-Occupational Exposure to Household Pesticides. Presented at the 4th International Conference on Indoor Air Quality and Climate, Berlin.

Lewis, R.G., Bond, A.E., Fitz-Simons, T.R., Johnson, D.E., and Hsu, J.P. 1986. Monitoring for Non-Occupational Exposure to Pesticides in Indoor and Personal Respiratory Air. Presented at the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, MN.

Matthews, T.G., Reed, T.J., Daffron, C.R., and Hawthorne, A.R., 1984. Environmental Dependence of Formaldehyde Emissions from Pressed-Wood Products: Experimental Studies and Modeling. Proceedings, 18th International Washington State University Particleboard/Composite Materials Symposium.

Meyer, B. 1983. Indoor Air Quality, Addison-Wesley Publishing Co.

Mowris, R.J. 1986. Analytical and Numerical Models for Estimating the Effect of Exhaust Ventilation on Radon Entry in Houses with Basements or Crawl Spaces. Applied Science Division, Lawrence Berkeley Laboratory.

Mowris R.J., and Fisk, W.J. 1988. Modeling the Effects of Exhaust Ventilation on ^{222}Rn Entry Rates and Indoor ^{222}Rn Concentrations. Health Physics Vol. 54, No. 5.

Nagda, N.L., Rector, H.E, and Koontz, M.D. 1987. Guidelines for Monitoring Indoor Air Quality, Hemisphere Press.

National Research Council (NRC). 1986b. Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects, National Academy Press.

Nazaroff, W. and Cass, G. 1986. "Mathematical Modeling of Chemically Reactive Pollutants in Indoor Air," in Environmental Science Technology, Vol. 20:924-34.

Nazaroff, W.W., Fuestel, H., Nero, A.V., Revzan, K.L., Grimsrud, D.T., Essling, M.A., and Toohey, R.E. 1984. Radon Transport into a Single-Family House with a Basement. Atmospheric Environment, 19(1):31-46.

New York State Energy Research and Development Authority (NERDA), and Niagara Mohawk Power Corporation (MMPC). 1985. Indoor Air Quality, Infiltration and Ventilation in Residential Buildings. NYSERDA Report 85-10.

Pandian, M. 1987. Evaluation of Existing Total Human Exposure Models. Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency.

Relewani, S.M., Moschandreas, D.J., and Billick, I.H. 1986. Effects of Operational Factors on Pollutant Emission Rates from Residential Gas Appliances. JAPCA, 36:1233-1237.

Repace, J.L. 1986. Indoor Concentrations of Environmental Tobacco Smoke: Models Dealing with Effects of Ventilation and Room Size. IARC Scientific Publication No. 81, Environmental Carcinogens -- Selected Methods of Analysis, Vol. 9.

Sakuma, H., Kusama, M., Munakata, S., Ohsumi, T., and Sugawara, S. 1984a. The Distribution of Cigarette Smoke Components between Mainstream and Sidestream Smoke II: Bases, in Beitr. Tabakforsch, Vol. 12, pp. 63-71

Sakuma, H., Kusama, M., Munakata, S., Ohsumi, T., and Sugawara, S. 1984b. The Distribution of Cigarette Smoke Components between Mainstream and Sidestream Smoke III: Middle and Higher Boiling Components, in Beitr. Tabakforsch, Vol. 12, pp. 63-71

Sheldon, L., Zelon, H., Sickles, J., Eaton, C., and Hartwell, T. 1988. Indoor Air Quality in Public Buildings, Volume II. Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency.

Sparks, L.E. 1988. Indoor Air Quality Model: Version 1.0. EPA Report no. EPA-600/8-88-097a.

Spengler, J.D., and Ferris, B.G. 1985. Harvard Air Pollution Health Study in Six Cities in the U.S.A. Tokai Journal of Experimental Clinical Medicine, Vol. 10, No.4.

Tucker, W. 1987. Chairman's Summary Session I -- Characterization of Emissions from Combustion Sources: Controlled Studies. Atmospheric Environment, Vol. 21, No. 2.

Tucker, W.G. 1986. Research Overview: Sources of Indoor Air Pollutants, IAQ-86 ASHRAE Conference, Atlanta, GA.

Wadden, R.A. and Scheff, P.A. 1983. Indoor Air Pollution, John Wiley and Sons.

Wallace, L.A., et al. 1983. Personal Exposure to Volatile Organic and Other Compounds Indoors and Outdoors -- The TEAM Study.

Wallace, L.A. 1987. The Total Exposure Assessment Methodology (TEAM) Study: Summary and Analysis: Volume 1.

World Health Organization (WHO). 1987. Air Quality Guidelines for Europe, WHO Regional Publications, European Series No. 23.

Wright, C.G., and Leidy, R.B. 1982. Chlordane and Heptachlor in Ambient Air of Houses Treated for Termites, in Bull. Env. Contam.

CHAPTER 3 - NON-CANCER HEALTH AND DISCOMFORT EFFECTS OF POOR INDOOR AIR QUALITY

This chapter summarizes the adverse health effects associated with exposure to poor indoor air quality, and provides detailed information on non-carcinogenic health impacts as well as acute discomfort effects. Carcinogenic risk assessments are the subject of Chapter 4.

In June 1987, EPA submitted a detailed report to Congress describing its plans for implementing an indoor air quality program. A major component of that report was Appendix A: Preliminary Indoor Air Pollution Information Assessment, prepared by EPA's Office of Research and Development. The Information Assessment provides detailed information on the current state of knowledge concerning indoor air pollutants, sources, and health effects and forms the basis for much of the information presented in this chapter. Where additional information has been added from other sources, these other sources are referenced.

3.1 SUMMARY OF POLLUTANTS, SOURCES AND HEALTH EFFECTS

Our knowledge of the major indoor air pollutants, pollutant sources, and potential health effects are summarized in Exhibit 3-1. The reader is reminded again that while Exhibit 3-1 is organized by individual pollutants and pollutant classes, pollutants are not breathed in isolation, but constitute complex and changing mixtures. Exposures to these mixtures may be more important than exposures to individual pollutants. The health effects of complex mixtures is not well understood (see discussion of pollutant mixtures in Section 3.3).

For many indoor pollutants, there is insufficient data to determine the exposure levels at which the listed effects would occur, and/or exposure information is insufficient for quantitative risk determinations. Controlled animal studies have been conducted for some pollutants the results of which can, under some circumstances, be extrapolated to humans. Animal and human health studies have, in some instances, allowed quantitation of the relationship between exposure to specific doses of an individual pollutant, and the severity or range of effect on health that can be expected from such exposure. Some human exposure data encountered in industrial work settings is also available for some pollutants. For most pollutants of concern, however, the dosages used for animal studies, as well as the exposures encountered by healthy workers in an industrial setting, are generally at higher levels than those that have been measured in non-industrial indoor environments.

Some epidemiologic studies have linked specific pollutants to specific changes in health or changes in mortality patterns in

Exhibit 3-1
Pollutants, Sources, and Health Effects

Pollutants	Sources	Health Effects
Radon	Soil, well water, some building materials	Cancer
ETS	Tobacco smoking	Cancer Irritation to mucous membranes Chronic & acute pulmonary effects in children Cardiovascular effects*
Biological Contaminants (viruses, bacteria, molds insects and arachnid excreta, pollen, animal and human dander)	Outdoors, humans, animals, (moist building areas are amplifiers for some)	Infectious diseases Allergic reactions Toxic effects
Volatile Organic Compounds (VOCs)	Paints, stains, adhesives, dyes, solvents, caulks, cleaners, pesticides, building materials, office machines	Irritation Neurotoxic effects Hepatoxic effects Cancer
Formaldehyde	ETS, UFFI, particle board, plywood, furnishings, upholstery	Irritation Allergy Cancer
PAHs	ETS, kerosene heaters, wood stoves	Cancer Irritation Cardiovascular effects Animal data show decreased immune function, atherosclerosis etiology
Pesticides	Pesticide application indoors and outdoors	Neurotoxicity Hepatotoxicity Reproductive effects
Asbestos	Asbestos cement, insulation, other building materials	Asbestosis Cancer

* The 1986 NRC Report and the Surgeon General's Report found the available data to be insufficient to draw firm conclusions about cardiovascular effects.

Exhibit 3-1 (cont.)
Pollutants, Sources, and Health Effects

Pollutants	Sources	Health Effects
Combustion gases		
CO	Combustion appliances, ETS, infiltrated exhaust	Increased frequency and severity of angina in patients Decreased work capacity in healthy adult males Headaches, decreased alertness, flu-like symptoms in healthy adults Exacerbation of cardiopulmonary dysfunction in compromised patients Asphyxiation
NO_2	Combustion appliances, ETS	Decreased pulmonary function in asthmatics Increased susceptibility to infection in animals Effect on pulmonary function in children, perhaps adults Synergistic effects with other pollutants in animals Animal studies indicate decreased immune capability, changes in anatomy and function of lung
SO_2	Combustion of fuels containing sulfur	Decreased lung function in asthmatics (in synergism with particles increased (doubled) airway resistance) Animal studies show decreased lung function
Particles		
Combustion particles	Combustion appliances, ETS	Cancer (soot, PAH adsorbed to particles) Irritation of respiratory tissues, eyes Decreased lung function alone and in conjunction with SO_2
Dust sprays, cooking aerosols	Personal activity	Unknown; can range from irritation to cancer

Source: EPA Indoor Air Quality Implementation Plan, Appendix A: Preliminary Indoor Air Pollution Assessment (EPA 1987).

human populations. Such studies are useful in identifying the hazards that such pollutants present indoors, even when specific exposure information concerning that pollutant in the indoor environment is not known, or when the full extent of the effect of a mixture containing such a pollutant can only be surmised.

3.2 POTENTIALLY SENSITIVE POPULATIONS

Certain individuals may be especially sensitive to indoor air pollutants because their age and/or health conditions may reduce their physiological defenses to the effects of indoor air pollutants. For example, some elderly have a reduced resistance to pulmonary irritants and infections, and have a higher incidence of preexisting pulmonary disorders; some new born and young children may also be especially sensitive to air pollutants. An estimate of the sizes of these potentially sensitive subpopulations is summarized in Exhibit 3-2. It is important to note that these subpopulations are not additive, e.g., the elderly and heart patient subpopulations clearly overlap.

3.3 NON-CANCER HEALTH AND DISCOMFORT EFFECTS

The potential health and discomfort effects of the major indoor air pollutants range from mild sensory irritation to acute toxicity, chronic organ damage, and death. The extent to which such effects actually occur depends on many factors, including the degree of exposure and the susceptibility of the individuals exposed. This section presents available information on non-cancer health impacts to the general population or to specific subpopulations. It must be emphasized that while it can be generally agreed that indoor air can and does cause many adverse health effects, quantitative relationships of the health impact from actual population exposures are not well established.

Few quantitative estimates are available for non-cancer health and discomfort effects. This does not imply that cancer is the most critical health endpoint for indoor air pollutants. To the contrary, many scientists believe that non-cancer health and discomfort are the most important for indoor air.

Available information on these effects for individual pollutants is summarized below and, except where otherwise indicated, is based on Appendix A of EPA's 1987 Indoor Air Quality Implementation Plan, Preliminary Indoor Air Quality Information Assessment (EPA 1987). Information on pollutant mixtures, biological contaminants, and on building sicknesses not necessarily associated with individual pollutants is presented in separate subsections.

Exhibit 3-2
Subpopulations with Potentially Increased Responsiveness to Indoor Air Pollutants

Subpopulation	Subpopulation Size	Percent of Population
Newborns[1]	3,731,000	1.5
Young children[2]	18,128,000	7.5
Elderly[3]	29,172,000	12.1
Heart patients[4]	18,458,000	7.7
Bronchitis[5]	11,379,000	4.7
Asthma[6]	9,690,000	4.0
Hay fever[7]	21,702,000	9.0
Emphysema[8]	1,998,000	0.8
Smokers[9]	69,852,000	29.9

---

[1] Live births in 1986; 1986 national population of 241,078,000 (USBC, 1988).

[2] Children under the age of five in 1986 (USBC, 1988).

[3] Persons over 65 or older in 1986 (USBC, 1988).

[4] Persons with heart diseases in 1986 (NCHS, 1987).

[5] Persons with bronchitis in 1986 (NCHS, 1987).

[6] Persons with asthma in 1986 (NCHS, 1987).

[7] Persons with hay fever or allergic rhinitis without asthma in 1986 (NCHS, 1987).

[8] Persons with emphysema in 1986 (NCHS, 1987).

[9] Persons 20 years of age and over who smoked in 1983; 1983 national population of 233,981,000 (PHS, 1985; USBC, 1985).

Effects of Individual Pollutants

Environmental Tobacco Smoke

On the basis of controlled experiments and field studies, nonsmokers are exposed to significant amounts of tobacco combustion products, as measured by urinary cotinine (Sepkovic et al., 1982; Matsukura et al., 1984; Wald and Ritchie, 1984; Jarvis et al., 1984; Greenburg et al., 1984; Surgeon General, 1986). These exposures amount to, in the most exposed individuals, levels 5-7% of those in smokers, and in the average case, about 1% of the levels in active smokers.

Non-cancer effects from environmental tobacco smoke include cardiovascular effects, increased susceptibility to infectious diseases in children, chronic and acute pulmonary effects in children, mucous membrane irritation, and allergic response (EPA 1987). While no definitive estimates of acute effects are available, respiratory symptoms such as wheezing, coughing, and sputum production are increased in children of parents who smoke. The increased risk is estimated to be between 20 and 80% depending on the symptoms being assessed and the number of smokers in the household (NRC 1986a). Since approximately 40% to 60% of children reside in households with smokers (CDC, 1986, and Bonham and Wilson, 1981), a significant number of children may be at increased risk for these effects.

Wells (1986, 1988) made preliminary estimates of the number of fatalities from heart disease and emphysema occurring in nonsmokers due to exposure to ETS. His preliminary assessment of the U.S. incidences of deaths from these diseases was based on estimates, obtained from epidemiological studies, of the relative risk resulting from exposure to ETS (i.e., the ratio of disease in those exposed to ETS versus those unexposed). The relative risks from the epidemiological studies were multiplied by nonsmoker death rates from an American Cancer Society study of mortality in 1,000,000 U.S. men and women (Hammond 1966). Estimated incidences of death from heart disease and emphysema were 32,000 and 170 cases, respectively.

Volatile Organic Compounds

More than 900 different volatile organic compounds have been identified in indoor air, and the health effects for some of these compounds are known, but the concentrations at which identified health effects occur are usually much greater than those measured in indoor air. Health effects reported for VOCs range from sensory irritation to behavioral, neurotoxic and hepatotoxic effects.

Concentration-response effects for aggregate mixtures of volatile organic compounds commonly found in indoor air have been studied in Denmark. Human subjects suffering from indoor climatic symptoms, but who were healthy and had no obvious medical reason for their complaints, were exposed to controlled concentrations of 5 and 25 mg/m^3. Significant effects of mucous membrane irritation and reduced ability to concentrate were experienced. Typical concentrations of total organic vapors and gases in new buildings range from 0.5 to 19 mg/m^3 (Molhave 1984, Molhave, et al., 1986). This suggests that exposure to mixtures of VOCs commonly found in building materials may be an important source of sick building syndrome complaints, but research is just beginning (see discussion below on sick building syndrome).

Formaldehyde and Pesticides

Irritation of mucous membranes from formaldehyde has been shown to occur in chamber studies at 0.1 to 0.2 ppm. Individuals sensitized to formaldehyde react allergically at concentrations of less than 0.1 ppm. Concentrations measured in mobile homes range from 0.03 to 8 ppm, with approximately 9,000,000 mobile home residents potentially exposed to formaldehyde for 10 to 24 hours per day. Concentrations in offices, public buildings, schools and homes can also range into irritatory levels, especially after remodeling or after installations of new furnishings and carpets.

Pesticides are by definition poisonous substances, affecting the nervous system, the liver, or the reproductive systems. Allergic reactions have been documented, though the extent of this impact is not known.

Combustion Gases

Carbon Monoxide: The EPA ambient air quality standard for carbon monoxide is 35 ppm for 1 hr duration and 9 ppm for 8 hours. However up to 60 ppm CO have been measured inside cars stopped in traffic jams, while up to 18 ppm were measured in public garages. Even when properly vented, homes that are very weather-tight may have downdrafts through the chimney which can cause dangerous levels of CO. Concentrations from faulty appliances have been measured in excess of 100 to 200 ppm. While no cause and effect relationship with the above concentrations is implied, it is useful to note that approximately 300 deaths due to carbon monoxide poisoning from consumer appliances are reported annually to the Consumer Product Safety Commission. These figures provide a general indicator of the hazard posed by exposure to carbon monoxide.

Nitrogen Dioxide and Sulfur Dioxide: Nitrogen dioxide is a deep lung irritant capable of producing pulmonary edema if inhaled in sufficient quantities. It should be noted that while results from both epidemiological studies of children exposed to gas stove emissions and controlled laboratory studies on adults are inconsistent, the Clean Air Scientific Advisory Committee of EPA, in review of these studies, concluded that preliminary evidence suggests that repeated exposure to 0.3 ppm NO_2 may cause increased bronchial reactivity in some asthmatics. Levels of NO_2 during cooking with gas or during use of kerosene heaters can exceed 0.53 ppm.

Sulfur dioxide exposure is associated with reduced lung function; however, there is an extremely large variation of sensitivity to sulfur dioxide. Asthmatics are at least one order of magnitude more sensitive than are otherwise normal individuals. Sulfur dioxide may act in concert with the particulate matter to double the airway resistance in infants and the elderly at concentrations of 0.75 ppm (1 min). Concentrations of 0.1 to 2.0 ppm (12 hour average) have been measured with unvented kerosene heaters using low-sulfur fuel.

Approximately 96 million persons may be exposed to emissions from gas stoves for an average of 4 hours per day, while approximately 7 million persons may be exposed to kerosene heater fumes for an average of 2 hours per day. Only a subset of these individuals are expected to be at risk and the extent of their risk is highly uncertain.

Pollutant Mixtures

As previously stated, pollutants are not breathed in isolation, but constitute complex and changing mixtures. The health effects may be additive, synergistic (combined effects are greater than the sum of effects from individual components), or antagonistic (combined effects are less than the sum of effects from individual components). In addition, the complexities involved with changes in composition of mixtures in time, in different spaces, and with changes in human activities, have not yet been studied.

Pollutant mixtures may play an important role in causing acute symptoms associated with the "sick building syndrome" (see discussion below) (Molhave 1984). In a controlled experiment conducted at the Institute of Hygiene in Denmark, 62 human subjects were subjected to a mixture of 22 organic vapors and gases that are common in residential building materials, and which are known upper airway irritants. The subjects were all healthy, without asthma, allergy, or chronic bronchitis. They were selected from a group contacted via the press, all suffering from "indoor climate symptoms", primarily irritation of the eyes and upper airways (Bach, Molhave and Pedersen 1984). When exposed to a total concentration of 5 and 25 mg/m^3, subjects showed significant mucous membrane irritation and memory impairment compared to exposure to clean air. These concentrations correspond to the average and maximum found in new Danish houses (Molhave 1984; Bach, et al., 1984). The concentrations of each of the individual experimental compounds were significantly below levels generally thought to cause effects. Exposure experiments between 0 and 5 mg/m^3 were not conducted. Reactions to mixtures of organic gases and vapors may also depend on other environmental factors as well as individual disposition to such symptoms (Molhave 1984).

Building Sickness

Acute health impacts, including those associated with sick building syndrome, are receiving increased attention, but because of data limitations, and difficulties in quantitation, little quantitative information is available on the extent of these impacts at this time. However, while data are insufficient to provide quantitative estimates of these risks, the data which are available are provided as an indicator of the potential risks associated with indoor air. The only quantitative non-cancer risk estimates which are available pertain to heart and lung diseases associated with environmental tobacco smoke.

In the 1970s, new energy-conserving building designs introduced tight building shells, inoperable windows, and centrally controlled ventilation systems which could operate with minimal introduction of outdoor air. These designs, combined with the emission of indoor air pollutants from synthetic building materials, cleaning and pest control products, office machines, smoking, and biological sources, have caused increases in indoor air pollution levels. Because these and other factors, complaints by building occupants have become increasingly more widespread. The physiological reactions to these pollutants, coupled with the psycho-social stresses of the modern office environment, and the wide range of human susceptibility to indoor air pollutants has led to some tentative classifications of acute building sickness: building related illness, sick building syndrome, and multiple chemical sensitivity. These emerging problems are the subject of continued inquiry in the scientific and medical community.

Building-related Illness

Building related illness is a term which refers to an illness brought on as a result of exposure to the building air, where symptoms of frank illness, including infection, fever, and clinical signs of pathology, are identified and an airborne pathway for the stressor is recognized (NRC 1987). Legionnaires' disease and hypersensitivity pneumonitis are examples of building-related illness.

Sick Building Syndrome

Sick building syndrome is a term which refers to a series of acute health and comfort effects which are experienced by a substantial percentage of the building occupants, the onset and relief of which are associated with entering and leaving the building, and where no specifically defined illness or etiology can be identified. The list of symptoms includes irritation of the eyes, nose, throat, and skin; neurotoxic symptoms, such as mental fatigue or headache; unspecific hyperreactions, such as runny nose or asthma-like symptoms; and odor and taste complaints. Generally, sensory irritation dominates the syndrome; systemic symptoms are infrequent (WHO, 1983; Molhave, 1987).

Investigators of sick building syndrome are typically unable to identify any single exposure factor exceeding a generally acceptable threshold and are therefore not able to identify any single specific cause of the problem. The causality, therefore, is often assumed to be multifactorial, involving combined environmental and psycho-social stresses (Molhave 1984). Contributing factors may include the additive or synergistic effect of multiple contaminants, the effect of climatic factors such as temperature, relative humidity, noise and lighting, and psycho-social stresses experienced by individuals at work and in non-work situations.

A full discussion of all the potential factors associated with sick building syndrome is beyond the scope of this report. Nevertheless, several studies of sick building syndrome in the United States and Europe offer some evidence of both building-related and psycho-social factors that may be associated with this problem. A major British study found higher prevalence rates of sick building syndrome complaints in air conditioned buildings (Hedge, et al., 1987; Harrison, et al., 1987). Among the air conditioned buildings, those with humidification systems, particularly spray or evaporative types, had the highest prevalence rates (Hedge, et al., 1987). However, only limited monitoring of air contaminants was conducted. Monitoring of air contaminants in the Harrison study was limited to particulate matter, fungi and bacteria, which did not correlate with symptom prevalences. No monitoring data were reported by Hedge.

A major multidisciplinary study in 14 Danish Town Halls (Skov and Valbjorn 1987; Valbjorn and Skov, 1987) found no association between sick building syndrome and ventilation characteristics, but found strong positive correlations with the age of the building, the total weight and potential allergenic portion of floor dust, the area of fleecy material, the open shelving per cubic meter of air, and the air temperature. The investigators also found higher health complaint rates to be associated with lower job status, being female, being involved in photoprinting activity, working with video display terminals, and handling carbonless paper.

Levin (1988) offers some preliminary interpretations to the results of various studies:

- Elevated temperature can directly affect occupant comfort, and indirectly affect contaminant concentrations by increasing offgassing of VOCs, particularly from large surface areas, such as ceiling tiles, fibrous linings of air ducts, fabrics covering walls, and free standing partitions. Microorganisms may also proliferate in higher temperatures and in buildings with reduced outside air supply.
- Many mechanical ventilation systems will reduce air flow and outside air supply when temperatures rise toward the upper end of the comfort range, thus reducing ventilation precisely when it is needed most to remove elevated contaminant levels and to provide evaporative cooling of occupants' exposed skin.
- Newer buildings are often constructed from softer, less durable materials on floors, ceilings, and walls, resulting in higher pollutant concentrations. Newer buildings are also designed to accommodate open offices with higher occupant densities, larger surface areas generating contaminants, and less physical, visual, and acoustical privacy. Open office areas also provide less personal control, and partitions may interrupt the flow of air necessary for health and comfort.
- Lower status jobs tend to offer less environmental variety and may be associated with windowless interior spaces. In addition, many air handling systems deliver outside air and ventilation primarily to the perimeter of the building, in order to control thermal loads from the exterior environment, with interior spaces receiving less outside air.

Multiple Chemical Sensitivity

In addition to building related illness and sick building syndrome, a considerable body of anecdotal data suggests the possibility that a small subset of the population has become sensitized to chemicals in the environment. Such individuals appear to repeatedly suffer acute reactions upon exposure to levels commonly found in indoor environments, exposures to which most persons would suffer no discernable adverse effects. Although such individuals report significant disability, the attribution to cause is hindered by lack of clear diagnostic criteria, data, or tools to evaluate the extent of the impairment. The situation often leads to a suspicion that the condition is psychosomatic in origin.

The condition has come to be known as multiple chemical sensitivities (MCS), but it is not known to what extent MCS affects health or productivity, or what the size of the affected population is.

MCS is a subject of considerable intraprofessional disagreement concerning the existence and etiology of this potential disorder (Cullen, 1987). While no widely accepted test of physiologic function has been shown to correlate with the symptoms, the sheer mass of anecdotal data is cause of concern.

In an attempt to focus discussion and facilitate potential research, Dr. Mark Cullen from the Yale University School of Medicine suggests that a working definition of multiple chemical sensitivity include seven major diagnostic features (Cullen, 1987):

1. The disorder is acquired in relation to some documentable environmental exposure(s), insult(s), or illness(es).
2. Symptoms include more than one organ system.
3. Symptoms recur and abate in response to predictable stimuli.
4. Symptoms are elicited by exposures to chemicals of diverse structural classes and toxicologic modes of action.
5. Symptoms are elicited by exposures that are demonstrable (albeit at low levels).
6. Exposures that elicit symptoms must be significantly below exposures known to cause adverse human response.
7. No single widely available test of organ system function can explain symptoms.

Building related illness, sick building syndrome, and multiple chemical sensitivities are increasingly being recognized as potentially serious, albeit untraditional, health and comfort consequences of modern indoor environments. But they are poorly understood and there is a lack of scientific consensus concerning the important environmental or physiological determinants of these problems. As a result, these problems create a dilemma for those charged with the clinical treatment of suffering individuals as well as for those responsible for the management and control of building environments.

Biological Contaminants

Airborne biological contaminants are present in all indoor and outdoor environments and emanate from a variety of sources, including plants, animals, and humans. Bacteria and viruses are brought into the indoor environment largely through human exhalations. Indoor appliances, such as air conditioners, humidifiers, and flush toilets, are often major sources of biological contaminants, as are water-damaged carpets or other furnishings. These appliances, especially room humidifiers, may function as fertile breeding grounds for microorganisms, and have been implicated in a number of cases of building-related illness. Molds and fungi may be brought in from outdoors and may proliferate in warm damp indoor environments.

Biogenic aerosols can produce direct toxicity, as with the mycotoxins produced by some molds and fungi, or they may be pathogenic (provoking infectious disease) or allergenic (provoking hypersensitive or allergic diseases).

Mycotoxins

Some molds are known to produce mycotoxins. Such toxins produce direct toxic effects as well as immunosuppression. At low concentrations, some mycotoxins produce gastrointestinal lesions, hematopoietic suppression, and suppression of reproductive function. Toxicity to the central nervous system produces symptoms such as anorexia, lassitude, and nausea. Trichocene mycotoxins can produce non-specific symptoms such as those described in "sick building syndrome". (EPA 1987).

Some fungi also produce mycotoxins which are known to be highly potent systemic poisons. The concentration of mycotoxins in the spores of toxigenic fungi are often very high. While the effects of these poisons are primarily known from their ingestion, it is reasonable to assume that these toxins have a systemic effect when inhaled, since inhalation more effectively allows systemic entry for dissolved substances. (EPA 1987).

Pathogens

Many pathogens, which are infectious agents, are communicated by airborne transmission. These agents induce serious diseases, including influenza, chicken pox, measles, pulmonary tuberculosis, and smallpox, which affect millions of people each year. An infected individual, however, is the source of the particular biological agent, and as such, these health effects are typically not considered building-related (Kreis and Hodgson 1984). Nevertheless, airborne transmission of infectious agents is believed to be related to the ventilation of buildings; a recent study involving four Army training centers demonstrated that the rates of acute febrile respiratory disease were 50 percent higher in modern barracks (that had been constructed with energy-efficient designs) than in older barracks (Brundage _et al._, 1988).

Some infectious bacteria, which proliferate in humidifiers, air conditioners, and in other building components, have caused building-related epidemics, including outbreaks of Legionnaires' disease, and Pontiac fever.

Legionnaires' disease is caused by _Legionella pneumophila_ which, in addition to affecting the lungs, may also involve the gastrointestinal (GI) tract, the kidneys, and the central nervous system. This illness was first identified during an epidemic at a Legionnaires' convention in a Philadelphia hotel in 1976, which affected 182 persons and caused 29 deaths. Since 1976, numerous building epidemics have been associated with this bacterium. Approximately 1-7 percent of persons exposed to L. pneumophila become ill with Legionnaires' disease. Sources of the bacterium include aerosols from cooling towers, evaporative condensers, and humidifiers, and dusts from landscaping and construction activities. (Kreiss and Hodgson 1984).

Pontiac fever, named after a 1968 building epidemic in Pontiac, Michigan, is caused by the same bacterium which causes Legionnaires' disease. Unlike Legionnaires' disease, however, Pontiac fever is a short term (two to five day) illness characterized by fever, chills, headache, and muscle ache, and sometimes coughing, sore throat, chest pain, nausea, and diarrhea. Pontiac fever is not fatal but nearly 100 percent of those exposed to the bacterium get the disease. No consensus exists as to why the same bacterial strain causes two distinct clinical syndromes. (Kreis and Hodgson 1984).

Allergens

Unlike infectious agents, which induce infections in normal individuals, allergenic agents do not affect most persons, but provoke an allergic (hypersensitive) reaction only in a small subset of the population (Solomon and Burge 1984). While some chemicals can provoke allergic responses, most allergens are biological and include both viable and nonviable agents. Viable organisms provoking such responses are molds, amoebae, algae, and bacteria. Nonviable agents such as house dust mite fecal pellets, cockroach feces, insect and arachnid dried hulks and body parts, animal danders, nonviable remains of molds and their spores, dried reentrained animal excretions such as saliva, sweat, urine and feces, pollens, and biogenic volatiles have also been identified as actors. Common allergic illnesses include allergic rhinitis, bronchial asthma, and hypersensitivity pneumonitis (EPA 1987).

Allergic rhinitis is characterized by nasal air passage obstruction, itching, sneezing and excessive secretion of mucus. Allergic rhinitis is commonly referred to as "hay fever" when it is seasonally related. Conjunctivitis, which involves irritation, itching, and reddening of the eyes, is often associated. Excessive mucus secretion and blocking of sinus and eustachian passages provide growth reservoirs where secondary bacterial infections may implant, thus predisposing individuals to bacterial infections in the upper airways (EPA 1987).

Bronchial asthma involves a recurrent narrowing of bronchioles and hypersecretion of thick mucus that can block airways, is accompanied by varying degrees of wheezing, shortness of breath, and coughing. Secondary bacterial infections can result in bronchitis and more sensitive reactions to irritants and other allergens (EPA 1987).

Hypersensitivity pneumonitis (extrinsic allergic alveolitis) is a serious acute immune reaction to sensitizing substances. It involves the production of large amounts of IgE antibody, cellular hypersensitivity, and the formation of interstitial granulomas. It causes filling and variable destruction of the alveoli by inflammatory cells (EPA 1987). With continued exposure irreversible pulmonary fibrosis and eventual pulmonary failure, ending in death, ensues (Reed 1981, and Solomon and Burge 1981, as cited in EPA 1987).

3.4 SUMMARY AND IMPLICATIONS

Health effects from indoor air pollution cover the range of acute and chronic effects, and include eye, nose, and throat irritation, respiratory effects, neurotoxicity, kidney and liver effects, heart functions, allergic and infectious diseases, developmental effects, mutagenicity, and carcinogenicity. Non-carcinogenic health effects may constitute the most significant indoor air quality problem.

Building sicknesses, such as sick building syndrome, building related illness, and multiple chemical sensitivity are issues of potentially great significance but are poorly understood. Additive or synergistic effects from pollutant mixtures, where concentrations of each individual compound are below its known health effect threshold, may help to explain some sick building syndrome complaints. Biological contaminants are a principal cause of building related illness, and can be the principal problem in some buildings. Building related illness can result in death, as in Legionnaire's disease, or serious infectious or allergic diseases. A considerable body of anecdotal evidence suggests that a small subset of the population has become sensitized to chemicals in the environment. The phenomenon is referred to as multiple chemical sensitivity, but little definitive scientific evidence is available.

References

Bach, B. Molhave, L., and Pederson, O.F., 1984. "Human Reactions During Controlled Exposures to Low Concentrations of Organic Gases and Vapours Known as Normal Indoor Air Pollutants: Performance Tests, in Indoor Air: Proceedings of the 3rd International Conference on Indoor Air Quality and Climate, Stockholm.

Bonham, G.S. and Wilson, R.W. 1981. Children's Health in Families with Cigarette Smokers. American Journal of Public Health, 71, 290-293.

Brundage, J.F., Scott, R.M., Lednar, W.M., Smith, D.W., and Miller, R.N., 1988. Building-Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees. Journal of the American Medical Association, Vol. 249, No. 14.

Bureau of the Census (BC). 1988. Statistical Abstract of the United States: 1988.

Bureau of the Census (BC). 1985. Statistical Abstract of the United States: 1985.

Center for Disease Control (CDC). 1986 Adult Use of Tobacco. Atlanta, GA.

Cullen, M. R., 1987. The Worker with Multiple Chemical Sensitivities: An Overview Workers with Multiple Chemical Sensitivities, Occupational Medicine, State of the Art Reviews, Volume 2, No. 4, Hanley and Belfus, Inc, Philadelphia.

Coburn, R.F., Forster, R.E., Kane, P. B., 1965. Considerations of the Physiological Variables that Determine the Blood Carboxyhemoglobin Concentration in Man. J. Clin. Invest. 44: 1899-1910 (as cited in EPA 1987).

Environmental Protection Agency. 1987. EPA Indoor Air Quality Implementation Plan, Appendix A: Preliminary Indoor Air Pollution Information Assessment, Office of Research and Development, EPA/600/8-87/014.

Greenburg, R.A., et al., 1984. Measuring the Exposure of Infants to Tobacco Smoke: Nicotine and Cotinine in Urine and Saliva. New Engl. J. Med. 310:1075-1078.

Hammond, C. 1966. Smoking in Relation to Death Rates of One Million Men and Women. Epidemiological Approaches to the Study of Cancer and Other Chronic Diseases, Haenszel, W., ed., NCI Monograph 19, pp. 127-204.

Harrison, J., Pickering, A.C., Finnegan, M.J., and Austwick, P.K. 1987. The Sick Building Syndrome - Further Prevalence Studies and Investigations of Possible Causes, Indoor Air'87. Proceeding of the 4th International Conference on Indoor Air Quality and Climate, Berlin.

Hedge, A., Wilson, S., Burde, P.S., Robertson, A.S., and Harris-Bass. 1987. Indoor Climate and Employee Health in Offices, in Indoor Air'87, Proceeding of the 4th International Conference on Indoor Air Quality and Climate, Berlin.

Jarvis, M.J., et al., 1984. Biochemical Markers of Smoke Absorption and Self-reported Exposure to Passive Smoking. J. Epi. and Comm. Health 38:335-339.

Kreiss, K., and Hodgson, M.J. 1984. Building-Associated Epidemics. Indoor Air Quality, Walsh, P.J., Dudney, C.S., and Copenhaver, E.D., eds. CRC Press.

Levin, H. 1988. Edifice Complex: An Anatomy of Sick Building Syndrome Control and Abatement. Presented at the Annual Meeting of the Air Pollution Control Association, Dallas, TX, June 24-24, 1988.

Matsukura, S. et al., 1984. Effects of Environmental Tobacco Smoke on Urinary Cotinine Excretion in Nonsmokers: Evidence for Passive Smoking. New Engl. J. Med. 311:828-832.

Molhave, L. 1984. Volatile Organic Compounds as Indoor Air Pollutants. Indoor Air and Human Health Proceedings of the 7th Life Sciences Symposium, Gammage R., et al., eds. Knoxville, Tennessee.

Molhave, L. 1987. The Sick Buildings - A Subpopulation Among the Problem Buildings, Indoor Air'87 Proceeding of the 4th International Conference on Indoor Air Quality and Climate, Berlin.

National Center for Health Statistics (NCHS). 1987. Current Estimates from the National Health Interview Survey: 1986.

National Institute for Occupational Safety and Health (NIOSH). 1987. "Guidance for Indoor Air Quality Investigations."

National Research Council (NRC). 1986a. Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects, National Academy Press.

National Research Council (NRC). 1986b. The Airliner Cabin Air Environment: Air Quality and Safety, National Academy Press.

National Research Council (NRC). 1987. Policies and Procedures for Control of Indoor Air Quality, National Academy Press.

Public Health Service (PHS). 1985. Health United States 1985.

Reed, C.E. 1981. Allergic Agents. Bull. New York Academy of Medicine. 57: 897-906.

Sepkovic, D.W., et al., 1986. Elimination in Smokers and in Passively Exposed Nonsmokers. J. Amer. Med. Assoc. 256:863.

Solomon, W.R and Burge, H.A. 1984. Allergens and Pathogens, Indoor Air Quality, Walsh, P.J., Dudney, C.S., and Copenhaver, E.D., eds., CRC Press.

Skov, P. and Valbjorn, O. 1987. The Sick Building Syndrome in the Office Environment: The Danish Town Hall Study, Indoor Air'87. Proceeding of the 4th International Conference on Indoor Air Quality and Climate, Berlin.

Surgeon General, 1979. Smoking and Health. U.S. Dept. of Health, Education, and Welfare, Washington, DC.

Surgeon General, 1986. The Health Consequences of Involuntary Smoking. U.S. Dept. of Health & Human Services, Washington, DC.

Wald, N.J., et al., 1986. Does Breathing Other People's Smoke Cause Lung Cancer? British J. Med. 293:1217-1222.

Wells, A.J. June 1986. Passive Smoking Mortality: A Review and Preliminary Risk Assessment. Presented at 79th annual meeting, Air Pollution Control Association, Minneapolis.

Wells, A.J. 1988. An Estimate of Adult Mortality in the United States from Passive Smoking. Environ. Internat. 14:in press.

Valbjorn, O. and Skov, P. 1987. Influence of Indoor Climate on the Sick Building Syndrome, Indoor Air'87 Proceeding of the 4th International Conference on Indoor Air Quality and Climate, Berlin.

World Health Organization (WHO). 1983. Indoor Air Pollutants: Exposure and Health Effects EURO Reports and Studies No. 78 Report on a meeting of the Working Group on Assessment and Monitoring of Exposure to Indoor Pollution, Copenhagen, WHO Regional Office 4.

CHAPTER 4 - CARCINOGENIC RISK ASSESSMENTS

Most of the risk assessments conducted to date have focused on carcinogenic effects. As stated in Chapter 3, this does not imply that non-cancer health effects are less important. To the contrary, risk assessments are normally conducted for carcinogenic effects largely because the methodology for assessing cancer risks has received the most attention. However, many scientists and policy makers believe that the non-cancer effects discussed in Chapter 3 are among the most important and pervasive for indoor air.

The only estimate established by EPA of the US population cancer incidence (in cases per year) for exposures to pollutants in indoor air is that for radon. Some information is also available on lifetime individual risks for formaldehyde for specific subsets of the U.S. population, based on exposure to a specific concentration of formaldehyde in indoor air. The remaining EPA estimates are unit risk estimates, providing information on the cancer risk that is estimated to occur from continuous lifetime exposure to a specific unit air concentration. These numbers, therefore, can only be used to determine risks to specific individuals in the population or to determine cancer incidences if combined with appropriate exposure data. Other assessments of the expected risks resulting from indoor air pollutants appear in the literature, but the adequacy of data, the assumptions, and the methodology used in these assessments have not been reviewed and evaluated by EPA, and their presentation in this report should not be interpreted as an endorsement. Rather, these estimates are presented solely to indicate to the reader what information and analysis has been conducted in the scientific community on this subject.

4.1 RISK ASSESSMENT METHODOLOGY

EPA Cancer Risk Assessment Methodology

The four elements of risk assessment are hazard identification, dose-response assessment, exposure assessment, and risk characterization. EPA (1986a) has established specific guidelines for performing risk assessments for carcinogens. A discussion of the four components of risk assessment, as they apply to carcinogenic risk assessment, is presented below.

Hazard Identification

Hazard identification consists of a review and analysis of all relevant chemical and biological information bearing on whether an agent may pose a carcinogenic hazard to humans. This review concludes with an evaluation of the overall weight of the evidence for carcinogenicity based on that analysis. Elements evaluated in hazard identification, in increasing level of importance, include:

(1) Physical and chemical properties, which affect a large number of factors in the risk assessment, such as absorption into the body, partitioning in various media, and decay rates;

(2) Structure-activity relationships, a comparison of the structure and activity of the chemical and its possible metabolites to those of known carcinogens and noncarcinogens, to evaluate the likelihood of carcinogenic activity;

(3) Pharmacokinetic interactions, a study of absorption, distribution, metabolism, and excretion of the chemical in animals and humans, used to determine important differences to consider in extrapolations between species;

(4) Routes of exposure, which may alter the carcinogenicity of the compound due to factors such as pharmacokinetic differences and interactions with other compounds;

(5) Short-term predictive tests, which detect chemical interactions with DNA and assess mutagenic activity, thus providing preliminary evidence of carcinogenic potential;

(6) Long-term animal bioassays, in which lower mammalian species (usually rodents) are used as surrogates for humans, to determine the potential tumorigenicity and/or carcinogenicity of the chemical; and

(7) Epidemiological studies, which are used to examine the association between human exposures to the agents and the incidence of cancer.

Of these seven elements, well-designed and well-conducted epidemiological studies provide the most direct information regarding the human carcinogenicity of a chemical. Unfortunately, adequate epidemiological data are not available for most chemicals due to several limitations. One is that large numbers of human subjects are often needed for statistically-defensible studies, especially if the exposures are low or rare or if the carcinogenic effect is small. Other complications are the long periods of time necessary for many cancers to be observed (usually greater than ten years) in the human population, the high cost of epidemiological studies, and the lack of accurate exposure data. Finally, data are not always available in epidemiologic studies to adjust for all risk factors which may have confounding influences, such as sensitive populations, socioeconomic conditions, and exposures to other chemicals (OSTP, 1984). Because of these limitations, estimates of human cancer risk must usually be derived from animal bioassay data and must rely on the other elements of hazard identification described above for evidence of presumptive carcinogenicity in humans.

Evaluating animal bioassay data for evidence of presumptive human carcinogenicity involves considering both the quality and adequacy of the data and the kinds and consistency of responses induced by a chemical. Criteria for the technical adequacy of animal bioassay studies have been published (e.g., OSTP, 1984; NTP, 1984). The criteria address issues such as the selection of appropriate species, strains, doses, routes of exposure, and study duration; animal care and diet; the selection of control groups; data collection and reporting; and the statistical evaluation of the results. Criteria such as these are useful in determining the scientific validity of the data obtained in the individual studies and how well each study serves as a surrogate for human studies. In evaluating the kinds and consistency of response induced by the chemical, the strength of the evidence that an agent may act as a human carcinogen is increased with:

(1) an increase in the number of animal species and strains showing a response, and whether one or both sexes respond;

(2) an increase in the number of tissue sites affected by the agent;

(3) the occurrence of a clear dose-response relationship;

(4) a high level of statistical significance of the increased tumor incidence in treated as compared to control groups;

(5) a dose-related decrease in the time to tumor formation or death with tumors; and

(6) a dose-related increase in the proportion of malignant versus benign tumors.

In characterizing the overall weight of the evidence for human carcinogenicity, the human and animal studies are evaluated both individually and in combination, followed by an analysis of all the supporting information to determine if the overall weight of the evidence should be modified. This analysis results in a grouping by EPA into one of the following categories:

(1) Group A (Known Human Carcinogen): Used only when there is sufficient evidence from epidemiological studies to support a finding that a causal relationship exists between exposure to the chemical and cancer;

(2) Group B (Probable Human Carcinogen): Used when there is sufficient evidence of carcinogenicity based on animal studies and limited epidemiological evidence (Group B1) or inadequate or no human data (Group B2);

(3) Group C (Possible Human Carcinogen): Used when there is limited evidence for carcinogenicity in animals and inadequate or no human data;

(4) Group D (Not Classified): Used when there is inadequate animal evidence of carcinogenicity and inadequate or no human data; and

(5) Group E (No Evidence of Carcinogenicity for Humans): Used when no evidence for carcinogenicity is found in at least two adequate animal tests in different species or in both adequate epidemiologic and animal studies.

The EPA classifications undergo review and evaluation by the EPA Science Advisory Board (SAB), and may be revised by EPA if differences in classification occur.

Although the above guidelines, based on the available animal and human data, are generally used in classifying chemicals, in some cases the known chemical or physical properties of a chemical and the results from short-term tests allow transfer of a chemical from groups B2 to B1, C to B2, or D to C.

Dose-Response Assessment

There are three major components to dose-response assessment: selection of the appropriate data based on factors such as the data's quality and its relevance to human modes of exposure, the choice of a relevant mathematical model to extrapolate from high to low doses, and the choice of the appropriate factors to be used when extrapolating data from animal studies to humans. Dose-response assessments may provide carcinogenic unit risk estimates (i.e., estimates of the cancer risk that would occur from exposure to a specific unit concentration of the agent). Unit risk estimates should be presented in those circumstances in which there is a reasonable possibility that an agent is carcinogenic to humans based on a weight of the evidence analysis (classification in group C or above); it is not necessary that the agent be causally associated with cancer in humans..

Selection of data for the assessment relies heavily on experience gained in the hazard identification. Whenever possible, estimates based on human epidemiological data are preferred. Use of these data forgoes the uncertainties of interspecies extrapolation. On the other hand, these studies may have several shortcomings, as discussed earlier. In the absence of well-designed and well-conducted epidemiological studies, data from well-conducted animal studies are used.

Selection of the appropriate animal data is made based on their perceived relevance to human exposures and response (e.g., similarities in pharmacokinetic parameters, exposure route, length of exposure, and/or site of action). Within this context, the most sensitive animal species and sex is used for estimating human cancer risk.

Exposures of the general population to carcinogens are generally much lower than those in animal or epidemiological studies. Animals are often exposed to levels 10,000 to 1,000,000 times that in the ambient environment, while levels in human occupational environments, those generally used for epidemiological studies, are typically 100 to 10,000 times that of nonoccupational groups. Therefore, it is necessary to use mathematical extrapolation models to estimate the carcinogenic response expected at lower exposure levels. Selection of the appropriate model for low-dose extrapolation of animal studies is critical because large differences in the projected risk may occur at low doses. Of the numerous models which have been developed, no single model is recognized as the most appropriate. The models or procedures employed should be consistent with any relevant biological data on the mechanisms of action of the carcinogen. When such data do not exist, the EPA guidelines recommend use, as appropriate, of the multistage procedure. This procedure is based on a currently-held theory that carcinogenesis results from a series of heritable changes or stages required for a normal cell to become malignant. The EPA uses a minor variation of this procedure called the linearized multistage procedure, which forces a linear term into the low-dose risk extrapolation. Use of this procedure results in a plausible "upper limit" to the risk (i.e. the true risk is not likely to exceed the value, but may be lower and even zero).

In addition to extrapolation of the dose-response data from high to low doses, dose-response assessments must estimate a human exposure which will result in an equal carcinogenic response in humans to that obtained in the animal studies. A variety of factors differ between humans and animals, including life span, body size, genetic variability, pharmacokinetic and pharmacodynamic parameters, and the exposure regimen. Because data to address these differences are generally limited, the usual approach to making interspecies comparisons is the use of standardized scaling factors for dose equivalence. For example, EPA uses mg/m^2 body surface area/day since certain pharmacological effects scale according to surface area. FDA uses a scaling factor based on body weight that leads to dose response extrapolations that are generally an order of magnitude less than the EPA approach.

The general outcome of the dose-response assessment is an estimate either of the cancer risk that would occur from exposure to a specific unit concentration of the agent (i.e., the incremental unit risk, often shortened to unit risk) or of the dose of the carcinogen that would result in a given level of increased risk.

Exposure Assessment

To obtain estimates of cancer risk for exposures to the population of interest, the results of the dose-response assessment must be combined with exposure estimates. At present, there is no single approach to exposure assessment. Each exposure assessment must be tailored to the needs of the problem at hand. However, EPA has prepared guidelines (EPA, 1986b) for exposure assessment which outline the following five major topics:

(1) Sources: an assessment of the relevant sources of the chemical to the environment, including an analysis of production, distribution, use, disposal, and environmental release;

(2) Exposure pathways and environmental fate: an analysis of how the chemical moves through the environment from the source to the exposed individual or population;

(3) Measured or estimated concentrations: an estimation of the environmental concentrations of the chemical available for exposure based on measured data, the use of mathematical models, or both;

(4) Exposed populations: an evaluation of populations and sensitive subpopulations (e.g., infants, the elderly, and the chronically ill) which may be exposed to the chemical by the various routes of interest; and

(5) The integrated exposure analysis: a set of exposure profiles which address, for each source, the size of the exposed population, and the routes, duration, frequencies, and intensities of exposure.

The final exposure assessment should be designed to be readily integrated with the dose-response assessment data. Generally, lifetime average daily exposures (LADEs) are calculated assuming that a high dose of a carcinogen received over a short time period is equivalent to a corresponding low dose spread over a lifetime. EPA will continue to use this assumption until more data or newer procedures become available. These exposures are then combined with an estimate of the additional lifetime unit risk from exposure to the carcinogen to characterize risk.

Risk Characterization

Risk characterization combines the results from the hazard identification, the dose-response assessment, and the exposure assessment to estimate the adverse health effects from pollutant exposure. Risk characterization is comprised of two parts. The first part involves numerically estimating the risk to human health. The second part involves developing a framework in which the uncertainties associated with these risk estimates can be characterized.

Presentation of numerical risk estimates vary with the needs of the program offices within EPA. In some cases, the unit risk or the dose associated with a particular level of risk will be presented. These values can then be compared with information in the exposure profiles to estimate the risk of particular exposures.

Generally, risks are reported in terms of additional lifetime risk estimates for individuals exposed to maximum and average levels of the agent or in terms of risks for an entire exposed population. For example, to obtain the individual lifetime risk for a person exposed to a particular concentration of a carcinogen, the incremental unit risk may be multiplied by the lifetime average daily exposure of that person. Population (or aggregate) risk, on the other hand, applies across the population of interest, and is expressed as expected increased cancer in the population over some specified time period (generally, annually).

Some risk estimates are prepared for exposure to multiple chemicals. In such cases, it is assumed that the population risks for each chemical may be added together, unless there is toxicological evidence to the contrary.

The predicted risk should be presented with an accompanying estimate of the uncertainty of the data from the hazard assessment, the dose-response assessment, and the exposure assessment. This evaluation provides the decision-maker with a better understanding of the impact of these uncertainties on the risk estimate.

4.2 VARIATIONS WITHIN RISK ASSESSMENTS

As discussed in the previous section, numerous variables are analyzed in performing a risk assessment, each variable having its own associated uncertainty. In addition, although the standard framework for performing a risk assessment does not vary (i.e., hazard identification, dose-response assessment, exposure assessment, and risk characterization), the methods used to perform each of these elements can vary widely based on factors such as the type of information available, its associated uncertainties, and its perceived scientific validity. Scientific assessments of the accuracy and relevance of information used for each of the variables in a risk assessment may diverge, resulting in vast differences in the final outcome of each risk assessment and its associated uncertainties.

Scientific disagreement regarding risk assessments can occur both in the proper classification of a carcinogen (i.e., the determination of the weight-of-the-evidence for carcinogenicity) and in the final determination of the quantitative risk estimate. An example of divergence of scientific opinion concerning classification is perchloroethylene. For perchloroethylene, the main issue concerning classification is centered around the evidence for carcinogenicity in the rat. The EPA Human Health Assessment Group (HHAG) has proposed to classify perchloroethylene as a Group B2 "probable human carcinogen" based on statistically significant increases in liver carcinomas in male and female mice, a marginally statistically significant increase of mononuclear cell leukemia and an increased incidence of normally rare kidney tumors in male rats, and supporting evidence showing that an epoxide metabolite of perchloroethylene is a mutagen.

The Halogenated Organics Subcommittee of the EPA Science Advisory Board (SAB), upon reviewing the HHAG's risk assessment, has questioned the evidence for carcinogenicity in the rat, initially concluding that perchloroethylene should be classified as a group C "possible human carcinogen." With respect to the kidney tumors, the Subcommittee questioned the diagnosis of neoplasia, and objected to combining benign and malignant tumors. With respect to leukemia, the Subcommittee questioned the diagnosis and evaluation of the disease and objected to the inclusion of preleukemic stages in the statistical analysis of tumor incidence. Concerning the increase of mouse liver tumors, the Subcommittee agreed that perchloroethylene caused these tumors but questioned their relevance to humans.

After a further review of the HHAG position regarding classification of perchloroethylene, the SAB Subcommittee has modified their classification, stating that perchloroethylene should be viewed as on the "continuum" between Groups B2 and C.

The HHAG is currently reevaluating its classification of this chemical, in response to the SAB review.

Variations in the estimation of the quantitative risk can come from differences of opinion regarding the hazard identification, the dose-response assessment, or the exposure assessment. Para-dichlorobenzene is another example of differing views regarding hazard identification. At this time, para-dichlorobenzene has been classified as a Group C carcinogen by EPA based on studies in laboratory animals using the oral route of exposure (52 FR 25690, July 8, 1987). However, in making this classification, EPA has stated that "the classification of para-dichlorobenzene as a Group B2 or Group C substance is a controversial one. EPA will reassess this classification as new information becomes available."

A second issue of controversy is the uncertainty involved in using the oral bioassay data to estimate risks from inhalation exposure. A para-dichlorobenzene inhalation bioassay was performed which failed to detect an increase in tumor incidence in rats. However, because of the short duration of exposure in the inhalation study (18 versus 24 months) and the possibility that a higher dose of para-dichlorobenzene may have resulted in a different response, the adequacy of this study has been questioned. Nevertheless, in view of these results and additional questions regarding the relevance of the tumors observed in the laboratory animals to tumor formation in humans, quantitative estimates of carcinogenic risks from para-dichlorobenzene, based on the oral exposure bioassays, are considered by EPA to be very uncertain. The EPA Office of Pesticide Programs (OPP) has required an industry-sponsored bioassay to further address the carcinogenicity of para-dichlorobenzene by the inhalation route.

There are also differences of opinion on both whether and how pharmacokinetic data should be factored into the analysis of carcinogenic risks, and whether pharmacokinetic models should be used only to extrapolate carcinogenic risks from high to low doses, or also to extrapolate between species. Recently, various models have been developed to relate an exposure (e.g., inhalation) to the corresponding dose at the organ level. This reflects the contention that carcinogenic activity is more directly the result of the delivered dose (i.e., the dose at the organ level) than the applied dose (i.e., the exposure level). Therefore, these models may more accurately equate an exposure to its corresponding carcinogenic risk. EPA has recently applied pharmacokinetic modeling to determine the risks from exposures to methylene chloride. The use of these models has had an impact on EPA's assessment of the risks from exposure to this compound, causing a 9-fold decrease in EPA's previous unit risk estimate.

One of the major sources of variations and uncertainties in cancer risk assessments is the choice of the data and methods used for low-dose extrapolations. Data from one study or from several different studies may be used in the analysis. Even when using data from one bioassay, results can vary widely due to factors such as the choice of a particular sex or tumor type, the grouping of data from several tumor types in the analysis, and the pooling of benign and malignant tumors. In addition, methods used for low-dose extrapolation of the same data set can result in differences of many orders of magnitude. Therefore, choice of an appropriate low-dose extrapolation model is important and should be based on an overall knowledge of the agent and its effects.

Risk assessments can also vary widely based on whether the unit risk estimate chosen is the "maximum likelihood estimate" (MLE) or the "upper confidence limit" (UCL). The MLE is a statistical estimate of the most likely value within the observed (i.e. high dose) range of the dose-response. It should be noted that the MLE for the low dose range is calculated by an extension of the MLEs in the high dose range and may therefore not represent the optimal value. The UCL is larger than the MLE and represents the upper confidence level of the risk (i.e., for the 95% UCL, 95% of the time, the true risk is not expected to exceed this value, and may be lower and even zero). Although the MLE and the UCL for many chemicals are within an order of magnitude, this is not always the case. An example of the wide variations which may occur due to this choice is formaldehyde, for which the EPA estimates of the MLE and UCL vary by six to seven orders of magnitude at very low doses.

Another source of variation and uncertainty is the exposure data used. For the same agent, the estimated exposures can vary widely depending on factors such as the monitoring protocol used, the types of modeling used, the parameters chosen to represent the frequency and duration of exposure, and the populations and subpopulations of concern and their locale. Likewise, averaging exposure over a lifetime (e.g., use of an LADE) may not characterize risks from acute exposures, where detoxification metabolic pathways are saturated at low levels.

In summary, different risk assessments for the same agent may diverge greatly due to the numerous variables analyzed and their associated uncertainties. An understanding of the number and types of elements that go into a risk assessment and their associated uncertainties are necessary to a complete understanding of the risk characterization presented.

4.3 EPA CANCER RISK ASSESSMENTS FOR INDOOR AIR POLLUTANTS

In this section of the report, a number of the cancer risk assessments that have been conducted by EPA for indoor air pollutants are discussed. Exhibit 4-1 presents a summary of cancer risk estimates for selected indoor air contaminants. An estimate of the annual cancer incidence resulting from indoor air pollution has only been provided for one pollutant, radon. The remaining estimates are unit risk estimates, providing information on the cancer risk that is estimated to occur from continuous lifetime exposure to a specific unit air concentration. These numbers, therefore, can only be used to determine risks to specific individuals in the population or to determine cancer incidences if combined with appropriate exposure data.

Estimates of annual cancer incidences for pollutants in indoor air, other than radon, have not presently been established by EPA. Estimates of lifetime individual risks for formaldehyde have been made only for subsets of the U.S. population, based on exposure to a specific concentration of formaldehyde in indoor air. Lifetime individual risk estimates for indoor air exposures to the other pollutants have not been established by EPA.

Risk estimates presented for radon, asbestos, and benzene are "maximum likelihood estimates" (MLEs) based on human epidemiological data. The unit risk estimates presented for the organic chemicals, with the exception of benzene, are based on animal bioassay data and represent the "upper-bound" estimate of the risk. A further discussion of the EPA risk estimates by pollutant type follows.

Radon

Assessing the total cancer risk to the general population for radon exposure is complicated by two factors. First, the distribution of radon levels in the U.S. is not well documented. Indoor radon levels vary widely according to region, building construction, and indoor air flow characteristics. Second, radon risk assessments are based on epidemiological data on male uranium miners who tended to be smokers. Nonetheless, EPA has attempted to predict the lung cancer deaths caused by exposure to typical levels of radon, classified by EPA as a Group A carcinogen.

The EPA Office of Radiation Programs (EPA, 1987a) has estimated the risk of death from lung cancer caused by exposure to indoor radon in four steps: (1) determining the radon decay product concentrations from the radon concentration; (2) estimating the cumulative radon decay product exposure; (3) converting the individual cumulative exposure to the lifetime risk; and (4) projecting the individual lifetime risks to the

Exhibit 4-1
EPA Cancer Risk Assessments

Pollutant	Unit Risk[1] (Classification)	Estimated Annual Excess Cancer Cases	Reference
RADON	2.3×10^{-4} to 9.2×10^{-4}/WLM(A)	20,000	EPA (1987a)
VOCs			
Benzene	8.3×10^{-6}/ug/m^3(A)	--	EPA (1988)
Methylene chloride	4.7×10^{-7}/ug/m^3(B2)	--	EPA (1988)
Chloroform	2.3×10^{-5}/ug/m3(B2)	--	EPA (1988)
Carbon tetrachloride	1.5×10^{-5}/ug/m^3(B2)	--	EPA (1988)
1,2-Dichloroethane	2.6×10^{-5}/ug/m^3(B2)	--	EPA (1988)
Trichloroethylene	1.7×10^{-6}/ug/m^3(B2)	--	EPA (1988)
Tetrachloroethylene	5.8×10^{-7}/ug/m^3 (B2/C)	--	EPA (1988)
FORMALDEHYDE	1.3×10^{-5}/ug/m^3(B1)	--	EPA (1987b)
PAHs			
Benz(a)-anthracene	8.9×10^{-4}/ug/m^3(B2)	--	EPA (1988)
Benzo(a)-pyrene (BaP)	1.7×10^{-3}/ug/m^3(B2)	--	EPA (1988)

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[1] Unit risk of the pollutant is the lifetime risk of contracting cancer per unit exposure.

Exhibit 4-1 (cont.)
EPA Cancer Risk Assessments

Pollutant	Unit Risk	Estimated Annual Excess Cancer Cases	Reference
PAHs (cont.)			
Dibenzo(a,h)-anthracene	1.4×10^{-2}/ug/m^3 (B2)	--	EPA (1988)
3-Methylcholanthrene	2.7×10^{-3}/ug/m^3 (B2)	--	EPA (1988)
PESTICIDES			
Aldrin	4.9×10^{-3}/ug/m^3 (B2)	--	EPA (1988)
Chlordane	3.7×10^{-4}/ug/m^3 (B2)	--	EPA (1988)
Dieldrin	4.6×10^{-3}/ug/m^3 (B2)	--	EPA (1988)
Heptachlor	1.3×10^{-3}/ug/m^3 (B2)	--	EPA (1988)
Lindane	3.8×10^{-4}/ug/m^3 (C)	--	EPA (1988)
ASBESTOS			
	1.6×10^{-4} to 2.3×10^{-3}/ 0.01 fib/ml$^{(2,3)}$ (A)	--	EPA (1986d)
	1.8×10^{-3} to 2.7×10^{-3}/ 0.01 fib/ml$^{(3,4)}$ (A)	--	EPA (1986d)

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[2] Lung cancer

[3] Fibers as measured by phase contrast microscopy

[4] Mesothelioma

entire U.S. population. Using data from uranium miners, the model estimated the carcinogenic unit risk from radon exposure to be a 1 - 4% increase in baseline risk per working level month (WLM). For the US population, the lifetime unit risk projected by the model is 2.3×10^{-4} to 9.2×10^{-4} per WLM. At an average U.S. lifetime radon exposure of 0.004 WL, this translates to between 5,000 and 20,000 excess lung cancer deaths per year. [Note: Based on revised estimates of risk and background exposure soon to be published by EPA, about 20,000 excess lung cancer deaths are projected annually.]

VOCs

As noted throughout this report, VOCs as a class of indoor air pollutants are poorly understood. Data are incomplete at best regarding the carcinogenicity and dose-response relationships for most of the VOCs that are detected indoors. Concentration levels to which people are exposed are highly variable. Periods of relatively intense exposure, which are not necessarily captured by a general monitoring survey, may make a significant contribution to lifetime exposure to a particular VOC. Identifying and characterizing the sources of indoor air pollutants is in an early stage of development. The identification and characterization of the size and makeup of populations exposed to different sources and indoor air concentration levels of VOCs is likewise in an early stage of development. Because of these limitations, EPA has not established either individual risk estimates or estimates of the number of cancer cases resulting from exposures to VOCs in indoor air environments.

EPA has established unit risk estimates for atmospheric exposures to many VOCs for other purposes (e.g., estimating risks from outdoor sources of these pollutants). Exhibit 4-1 presents EPA's unit risk estimates for benzene and several halogenated hydrocarbons. Although the unit risk estimates for these VOCs represent only a small fraction of those available for indoor air pollutants, they were selected because the compounds are frequently detected in indoor environments.

Formaldehyde

EPA (1987b) has classified formaldehyde as a probable (B1) human carcinogen based on sufficient animal and limited human evidence, and other supporting data. The upper-bound (UB) unit risk estimate for a lifetime ambient exposure to 1.0 ug/m^3 is 1.3×10^{-5}. Using this unit risk estimate, EPA has calculated an upper-bound lifetime cancer risk estimate of 2×10^{-4} for residents of mobile homes who are exposed for ten years to an average level of 0.10 ppm, or twice the estimated background level of 0.05 ppm; and 1×10^{-4} (UB) for residents of some conventional homes who are exposed for ten years to an average level of 0.07 ppm.

The corresponding maximum likelihood estimates (MLEs) for these exposures are much lower; 2×10^{-10} and 6×10^{-11}, respectively.

PAHs

EPA unit risk estimates for four PAHs found in indoor air are presented in Exhibit 4-1. These four PAHs are classified as "probable human carcinogens" (Group B2).

Pesticides

EPA has computed unit risk estimates, based on animal studies, for several of the major pesticides commonly detected indoors (Exhibit 4-1). With the exception of lindane, classified C, these pesticides are classified as B2 carcinogens.

Asbestos

EPA has listed asbestos as a Group A human carcinogen based on human epidemiological data. Data developed since the early 1970's, from large population studies with long follow-up, have strengthened the association of asbestos exposure with cancer in occupational settings. However, because of large uncertainties in extrapolating the occupational data to levels measured in the environment, estimates of risks from asbestos at low concentrations should be viewed with caution (EPA 1986d).

EPA (1986d) has estimated the unit risks of lung cancer and mesothelioma from asbestos exposure (Exhibit 4-2). These two cancers are the most important causes of death among asbestos-exposed individuals.

Exhibit 4-2
Risks ($\times 10^{-6}$) from Lifetime Asbestos Exposure to 0.01 Fibers/ml

Population	Lung Cancer	Mesothelioma
Female Smokers	1,500 (150-15,000)	2,520 (126-50,400)
Female Nonsmokers	164 (16.4-1,640)	2,720 (136-54,400)
Male Smokers	2,380 (238-23,800)	1,810 (91-36,200)
Male Nonsmokers	185 (18.5-1,850)	2,200 (110-44,000)

Source: EPA (1986d)

4.4 ADDITIONAL RISK ASSESSMENTS FOR INDOOR AIR POLLUTANTS

In this section of the report, the additional information available in the literature on the risks from exposure to pollutants in indoor environments is described. It should be noted that the studies presented in this section of the report have not generally undergone any form of critical review by EPA. More importantly, EPA has not provided a detailed written evaluation of these studies, examining their strengths and weaknesses in addressing a quantitative analysis of the level of risk from indoor air pollutants. From a cursory analysis, it is clear that some aspects of these analyses would not be acceptable to EPA [e.g., Tancrede et al.'s use of acute lethality data (LD50s) to estimate carcinogenic unit risk estimates for chemicals without bioassay data]. Therefore, EPA does not necessarily agree with the study designs used or with the conclusions reached by the authors of these assessments. Nevertheless, risk assessments prepared outside the Agency are presented here because, in many cases, they represent the only quantitative estimates of the individual risks or annual cancer incidences presently available for certain indoor air pollutants.

As discussed above, estimates of quantitative risk are subject to large variations, due to uncertainties occurring at each step in the analysis. These variations are apparent in many of the studies presented here, emphasizing the large uncertainties associated with these assessments.

Exhibit 4-3 summarizes the risk estimates for indoor pollutants obtained from sources outside the Agency. Estimates are provided for radon, ETS, VOCs, formaldehyde, and asbestos. Estimates for radon and asbestos are unit risk estimates based on human epidemiological data. Estimates for radon fall within a factor of two of the range of EPA unit risk estimates, presented earlier. EPA unit risk estimates for asbestos are within the range of estimates presented by others. However, it should be noted that the similarity of these estimates to EPA-generated estimates does not lend any particular credence to their validity.

Several estimates of the annual cancer incidence from ETS exposure, based on human epidemiological studies, are also presented. The estimates range from 12 to 5,200 cases per year.

The risk associated with exposure to VOCs has not been well-studied because of the number and diversity of these compounds, and a scarcity of exposure data for indoor air environments. Two investigators, however, have estimated the additive individual risk posed by exposure to typical levels of several VOCs in indoor air. Another investigator has estimated that the additive annual cancer incidence from exposure to six

Exhibit 4-3
Non-EPA Cancer Risk Assessments

Pollutant	Unit Risk[1]	Excess Ind. Lifetime Risk (x 10^{-6})[2,3]	Estimated Annual Excess Cancer Cases	Reference
RADON	3.5 x 10^{-4}/WLM	--	--	NRC (1988)
	1.3 x 10^{-4}/WLM	--	--	NCRP (1984)
ETS	5 x 10^{-5}/person-year/mg tar/day	--	5,000 +/- 300(4)	Repace & Lowrey (1985a, 1986, 1987)
	--	--	12(4)	Arundel et al. (1987)
	--	3,900-9,900	2,500-5,200(4)	Robins (1986)
	--	--	3,000(4)	Wells (1988)
	--	--.	11,000(5)	Wells (1988)
VOCs				
6 VOCs	--	--	1,000-5,000	Wallace (1985)
9 VOCs (NJ)	--	19,000-30,000 (mean)(6) 46,000-48,000 (98th perc.)(6)	--	Tancrede et al. (1987)

NOTE: The studies presented in this Exhibit have not been critically evaluated by EPA for their strengths and weaknesses in addressing a quantitative analysis of the level of risk from indoor air pollutants. Therefore, EPA does not necessarily agree with the study designs used or with the conclusions reached by the authors of these assessments.

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[1] Unit risk of the pollutant is the lifetime risk of contracting cancer per unit exposure.

[2] Excess individual lifetime risk is the risk of death (over and above normal risk) due to lifetime exposure to the pollutant.

[3] Exposures on which these values are based are discussed in the text.

[4] Lung cancer

[5] Non-lung cancers

[6] Tancrede and coworkers calculated mean and 98th percentile values assuming that both exposure and risk were random variables which can each take on a range of values, some more probable than others. This approach varies from EPA's approach, where a specific "maximum likelihood estimate" or "upper-bound" unit risk estimate is multiplied by an individual exposure level.

Exhibit 4-3 (cont.)
Non-EPA Cancer Risk Assessments

Pollutant	Unit Risk	Excess Ind. Lifetime Risk (x 10^{-6})[2,3]	Estimated Annual Excess Cancer Cases	Reference
VOCs (cont.)				
19 VOCs (CA)	--	2,000 (mean)(6) 11,000 (98th perc.)(6)	--	Tancrede et al. (1987)
15 VOCs	--	280-1,500	--	McCann et al. (1986)
FORMALDEHYDE	1.1 x 10^{-1}/ mg/kg-day (3.3 x 10^{-5}/ ug/m^3)	34,000 (mean)(6) 240,000 (98th perc.)(6)	--	Tancrede et al. (1987)
	--	4-9,500	--	McCann et al. (1986)
ASBESTOS				
	7.5 x 10^{-5} to 1.6 x 10^{-3}/ 0.01 fib/ml(4,7)	--	--	NAS (1984), as cited in EPA (1986d)
	2.3 x 10^{-4}/ 0.01 fib/ml(7,8)	--	--	NAS (1984), as cited in EPA (1986d)
	1.6 x 10^{-4} to 1.6 x 10^{-3}/ 0.01 fib/ml(4,7)	--	--	CPSC (1983), as cited in EPA (1986d)
	1.7 x 10^{-3} to 2.7 x 10^{-3}/ 0.01 fib/ml(7,8)	--	--	CPSC (1983), as cited in EPA (1986d)
	4 x 10^{-6} to 7.6 x 10^{-4}/ 0.01 fib/ml(4,7)	--	--	Ontario Royal Commission (1984), as cited in EPA (1986d)

NOTE: The studies presented in this Exhibit have not been critically evaluated by EPA for their strengths and weaknesses in addressing a quantitative analysis of the level of risk from indoor air pollutants. Therefore, EPA does not necessarily agree with the study designs used or with the conclusions reached by the authors of these assessments.

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[7] Fibers as measured by phase contrast microscopy

[8] Mesothelioma

Exhibit 4-3 (cont.)
Non-EPA Cancer Risk Assessments

Pollutant	Unit Risk	Excess Ind. Lifetime Risk (x 10^{-6})[2,3]	Estimated Annual Excess Cancer Cases	Reference
ASBESTOS (cont.)				
	1.4×10^{-5} to 1.9×10^{-3}/ 0.01 fib/ml(7,8)	--	--	Ontario Royal Commission (1984), as cited in EPA (1986d)
	8.6×10^{-5} to 2.9×10^{-3}/ 0.01 fib/ml(4,7)	--	--	Advisory Committee on Asbestos (1979), as cited in EPA (1986d)
	2.5×10^{-4}/ 0.01 fib/ml(4,7)	--	--	Doll and Peto (1985), as cited in EPA (1986d)
	5.6×10^{-5}/ 0.01 fib/ml(7,8)	--	--	Doll and Peto (1985), as cited in EPA (1986d)
	6.8×10^{-5} to 1.5×10^{-3}/ 0.002 fib/ml(4,7)	--	--	Breslow et al. (1986)
	7.8×10^{-4}/ 0.002 fib/ml(7,8)	--	--	Breslow et al. (1986)

NOTE: **The studies presented in this Exhibit have not been critically evaluated by EPA for their strengths and weaknesses in addressing a quantitative analysis of the level of risk from indoor air pollutants. Therefore, EPA does not necessarily agree with the study designs used or with the conclusions reached by the authors of these assessments.**

specific VOCs in indoor air ranges between 1,000 and 5,000 cases per year.

Unit risk estimates and individual risk estimates for formaldehyde vary widely, apparently due to the non-linearity of the dose-response curve for this chemical. EPA risk estimates (both the MLE and the upper-bound estimates) are generally lower than the estimates provided by other sources.

Finally, the carcinogenic risks from exposure to particulate matter, biological contaminants, and the combustion gases have not been addressed. A further effort is clearly needed in these areas in assessing the overall risks from indoor air pollution. The studies summarized in Exhibit 4-3 are discussed in greater detail below.

Radon

Two groups, in addition to EPA, have provided unit risk estimates for radon exposure based on epidemiological data for male uranium miners. The National Research Council (NRC, 1988), in the BEIR IV Report, estimated a unit risk for radon exposure of 3.5×10^{-4} per WLM, based on data from four studies of uranium miners. The National Council on Radiation Protection and Measurement (NCRP, 1984), estimated the unit lung cancer risk from lifetime exposure to radon of 1.3×10^{-4} per WLM. These estimates are within a factor of two of the range of unit risks established by EPA.

Environmental Tobacco Smoke

In 1986, the U.S. Public Health Service (Surgeon General, 1986) and the National Research Council (NRC, 1986) concluded that environmental tobacco smoke (ETS) is a cause of lung cancer and other disease in nonsmokers. Tobacco smoke intentionally inhaled is known to cause the premature deaths of 1000 smokers per day, from lung cancer and other cancers, cardiovascular diseases, and respiratory diseases (Surgeon General, 1979). Independent scientific committees organized by the Surgeon General and National Research Council (Surgeon General, 1986; NRC, 1986), in reviewing thirteen epidemiologic studies that have implicated ETS as a cause of lung cancer in nonsmokers, have judged these studies to prove causality between ETS exposure and lung cancer. Several investigators have estimated the annual incidences of lung cancer and other cancers resulting from exposure to ETS. A discussion of some of these studies is provided below.

Robins (1986) estimated U.S. lung cancer death rates from ETS by combining data on urinary cotinine dosimetry and estimates of the relative risk of passive smoking, as well as by fitting the multistage procedure to the data on the lung cancer experience of active smokers. Based on extrapolations from urinary cotinine, Robins estimated a range of exposure for nonsmokers to ETS of from 0.1 to 2.8 cigarettes per day (cpd). Estimates for nonsmokers with smoking spouses ranged from 0.4 to 2.8 cpd, and estimates for those with nonsmoking spouses ranged from 0.1 to 0.9 cpd.

Based on urinary cotinine and epidemiological studies showing a relative risk of 1.3 for passive smoking, Robins (1986) estimated 1770 deaths per year in women and 720 deaths per year in men, for a total of about 2,500 U.S. lung cancer deaths per year from ETS. Based upon the multistage procedure and the risks of lung cancer from active smoking, Robins estimated about 5,200 US deaths per year, 3,320 in females, and 1,940 in males. [However, it should be noted that extrapolations of the data on cancer risks from smokers to nonsmokers are uncertain. One problem with this approach is that smokers are a very high exposure group in whom the normal pulmonary defense mechanisms are overwhelmed (e.g., paralysis of respiratory cilia). Nonsmokers may not be exposed to high enough levels for such effects to occur and they may be at risk from different components of the smoke than are smokers and as such there may be considerable uncertainty in using tumor data in smokers to extrapolate to nonsmokers]. The range of Robin's estimates is from 2,500 to 5,200 lung cancer deaths per year.

Robins also estimated that the lifetime lung cancer death risk to lifelong nonsmokers from ETS ranges from 4×10^{-3} to 1×10^{-2}, and that the estimated lifetime lung cancer death risk to ex-smokers (who smoked for about 25 years and quit at age 45) from ETS is from 5×10^{-3} to 2×10^{-2}. Robins estimates are adjusted for "true relative risk", which accounts for the fact that nonsmokers in most epidemiological studies of passive smoking and lung cancer who are termed "unexposed" by virtue of having a nonsmoking spouse indeed have finite urinary cotinine, generated by exposures outside the home (e.g., the workplace).

Repace and Lowrey (1985a) assessed nonsmokers' risk of lung cancer due to respirable particulate (RSP) exposure from ETS. RSP exposures were estimated from a model and from empirical data. Lung cancer response was estimated from epidemiologically assessed, age-standardized differences in lung cancer mortality rates between two demographically comparable cohorts of lifelong nonsmokers. One of these cohorts, Seventh Day Adventists (SDAs), has a lifestyle with a high percentage of restrictions on smoking at home and at work relative to the other cohort, demographically comparable nonSDAs.

Repace and Lowrey (1985a) estimated that 4,700 lung cancer deaths occurred annually in lifelong nonsmokers and ex-smokers due to ETS exposure in the home and the workplace among the 62.4 million nonsmokers aged $\geq$ 35 years. The initial calculation did not differentiate between male and female nonsmokers, and age-standardized the calculation to the entire US population, which included smokers. A later refinement for these factors estimated 1,441 male nonsmoker and 3,450 female nonsmoker deaths, for a revised total of about 4,900 lung cancer deaths per year (Repace and Lowrey, 1986; 1987). Repace and Lowrey (1985a, 1986, 1987) estimated the uncertainty in their risk estimate at ± 300.

The unit risk estimate for Repace and Lowrey's studies was 5×10^{-5} lung cancer deaths per person-year at risk, per mg of exposure to tobacco tar per day, with the average exposure estimated at 1.4 mg of tar daily. A lifetime risk of about 2×10^{-2} to the most-exposed population was estimated. The loss of life expectancy for lung cancer mortality, averaged over the population, was estimated to range from 15 to 148 days, and the loss of life expectancy per fatality was estimated at 17 ± 9 years.

Arundel et al. **(1987)** estimated particulate tobacco smoke exposure from empirical data, and response from the lung cancer risks in smokers. By factoring in the ratio of estimated relative deposition of tar in the lungs of smokers and nonsmokers, and linearly extrapolating to the estimated exposure levels of nonsmokers from the exposure levels in smokers, Arundel et al. estimated 12 lung cancer deaths per year from passive smoking. However, it should be noted that while tar deposition in nonsmokers may be far less than in smokers, other putative carcinogens may be more concentrated in the smoke to which nonsmokers are exposed. Arundel et al. suggested that the differences between their estimates and those based upon epidemiologic methods in nonsmokers may be due to bias in the epidemiology (unspecified), a supralinear relationship between exposure and risk, or a greater carcinogenicity for sidestream relative to mainstream smoke.

Wells (1986, 1988) calculated the risks for nonsmokers of lung cancer and other cancers based on epidemiological data on adult mortality from passive smoking. A preliminary risk assessment of U.S. passive smoking deaths from cancer was made by applying the risk ratios from the epidemiology studies to estimates of the exposed population and to non-smoker death rates from an American Cancer Society study of mortality in one million U.S. men and women (Hammond, 1966). Wells (1988) estimated 3000 lung cancer deaths per year in lifelong nonsmokers aged ≥ 45 yrs and 11,000 deaths from other cancers.

Kuller et al. **(1986)** constituted a workshop panel assembled to review the data from the epidemiologic studies of passive smoking. The Workshop on the Contribution of Airborne Pollutants to Respiratory Cancer was sponsored by the Interagency Task Force on Environmental Cancer and Heart and Lung Disease, established by the Clean Air Act Amendments of 1977, and chaired by EPA. The panel concluded that data indicate that "the greater number" of an estimated 6,000 to 8,000 lung cancers in lifelong nonsmoking women is probably related to environmental tobacco smoke.

In summary, estimates of annual lung cancer cases in nonsmokers resulting from passive smoking range from 12 to 5,200. Most of the estimates fall between 2,500 and 5,200 lung cancer deaths per year (see Exhibit 4-3).

Volatile Organic Chemicals

As discussed above for EPA VOC risk assessments, limited data are available for assessing risks from indoor air exposures to these chemicals. As a consequence, there have been few risk assessments conducted for VOCs in indoor environments, either individually or as a group. Those that have been done have combined available personal exposure or indoor air monitoring data for specific VOCs with unit risk estimates for these compounds. Each of these studies has determined the additive risk posed by the chemicals evaluated, although it is not clear if these risks are additive, or whether synergistic or antagonistic effects occur in indoor air mixtures. It should be noted that the studies have addressed only a small subset of the VOCs present in indoor air; a much more comprehensive study is needed to fully evaluate these risks. A summary of the available studies is provided below.

Wallace (1985) used 24-hr personal exposure monitoring data from the EPA TEAM study to construct a risk assessment for benzene, chloroform, carbon tetrachloride, trichloroethylene, tetrachloroethylene, and para-dichlorobenzene in indoor air. This personal exposure monitoring data was chosen to apply to 700,000 residents of four states (New Jersey, California, North Carolina, and North Dakota), but was employed in this risk assessment as representative of the total U.S. population. In addition, data from the former two states were assumed to represent exposures to individuals in metropolitan areas, while data from the latter two states were assumed to represent those in non-metropolitan areas.

Lifetime average exposures were estimated based on the limited monitoring data available (one to three 24-hr air monitoring samples for each of 600 individuals monitored in the study), but Wallace stated, based on the variation across five sampling areas, that the error in the mean value may not be more than a factor of two. [It should be noted that the use of personal monitoring data, rather than indoor air monitoring data, may over- or underestimate risks from indoor air, since exposures during the periods spent in other settings (e.g., outdoor or industrial) would be included in the total personal exposure.

However, data indicate that individuals spend the majority of their time indoors.]

Of these six chemicals, only benzene is a known human carcinogen (EPA Group A). The rest are animal carcinogens. Chloroform, carbon tetrachloride, and trichloroethylene have been classified by EPA as Group B2 human carcinogens. As discussed earlier, the classification of tetrachloroethylene into either Group B2 or Group C is controversial. Para-dichlorobenzene has been classified in Croup C.

Two separate sets of unit risk estimates were used by Wallace. The first set relied on EPA unit risk estimates which were available for five of the six chemicals (i.e., all but para-dichlorobenzene). Wallace's estimate for benzene is based on a "maximum likelihood estimate" (MLE) from human epidemiology data; all other estimates are "upper-bound" (UB) estimates based on animal studies. In these latter estimates, it should be noted that the lower bound is always zero, allowing for the possibility that the chemical is not in fact a human carcinogen. Based on the EPA unit risk estimates, estimates of individual risk for the VOCs studied ranged from 5×10^{-6} to 1.6×10^{-4}.

The second set of risk estimates was based on unit risk values (MLEs and upper-bound) developed by Tancrede and coworkers at Harvard. The EPA and Harvard unit risk estimates varied widely (up to 30-fold). For para-dichlorobenzene, two unit risk estimates (high and low) were calculated based on NTP bioassay data for the mouse.

To determine the combined risk from these six VOCs in indoor air, Wallace summed estimates of risk for each specific chemical. He concluded that the annual cancer incidence ranged from about 1,000 cases using CAG estimates to about 5,000 to 7,500 cases using the Harvard upper-bound estimates. The Harvard MLEs ranged from 1,600 to 2,400 cases per year. Overall, Wallace estimated that about 1,000 to 5,000 excess cancer cases per year could be attributable to the six VOCs studied.

A large portion of the Harvard estimates, however, are due to estimates for para-dichlorobenzene. As discussed earlier, estimates of the quantitative risks from inhalation of para-dichlorobenzene are considered by EPA to be very uncertain since adequate inhalation bioassay data are not available. EPA is currently requiring industry to perform an inhalation bioassay on the chemical in order that risks by the inhalation route may be more adequately addressed. Excluding estimates for para-dichlorobenzene, the Harvard additive risks would approximate 1,000 cases using the MLE estimates and 3,500 cases using the upper-bound estimates.

Tancrede et al. (1987) presented individual risk estimates for 9 and 19 VOCs that had been detected in EPA TEAM studies of residences in New Jersey and California, respectively. The investigators reported that they deliberately made overestimates of cancer risks to individuals by assuming: 1) that every chemical poses such a risk, and 2) that the relationship between exposure and risk is linear. In presenting this conservative assessment of risk, Tancrede et al. estimated risks for some chemicals for which EPA has not established an Agency position on carcinogenicity (e.g., n-octane, n-decane, n-undecane, n-dodecane, ortho- and meta-dichlorobenzene, 1,1,1-trichloroethane, xylenes, ethylbenzene, and alpha-pinene).

Unit risk estimates were computed by several different means, including: 1) human epidemiological data (benzene), 2) a procedure based on the TD_{50}, the dose leading to 50% lifetime tumor incidence in NTP/NCI bioassays (carbon tetrachloride, trichloroethylene, tetrachloroethylene, chloroform, 1,2-dichloroethane, styrene, 1,4-dioxane); 3) use of a maximum likelihood technique procedure for NTP/NCI data (ortho-dichlorobenzene, 1,1,1-trichloroethane) or other bioassays (ortho- and meta/para-xylene, ethylbenzene), when the TD_{50} had not been calculated; and 4) by analogy with other chemicals, using theoretical methods based on LD_{50}s (m-dichlorobenzene, alpha-pinene) or other toxicological parameters (n-octane, n-decane, n-undecane, n-dodecane). The investigators acknowledge that the latter estimates may be "very uncertain, but can occasionally be bounded above by results of more direct experiments with negative outcomes." (The use of theoretical methods based on noncarcinogenic effects to estimate carcinogenic unit risks would not be acceptable to EPA.)

Exposure data used in the risk assessments were overnight personal exposure samples, which were assumed to represent continuous lifetime exposures. These data are probably more representative of indoor exposures than the 24-hr samples used by Wallace (1985). However, the data are limited (49 samples from New Jersey, representing an estimated 94,000 individuals; and 112 samples from California, representing an estimated 359,000 individuals). In addition, to be conservative, the investigators deliberately chose samples collected in winter when concentrations may have been higher than in other seasons.

Tancrede et al. treated both potency and dose as random variables which can take on a range of values, some more probable than others. They stated that this emphasis on random variability is an important difference from the EPA approach. The additive mean individual risk (i.e., the sum of the mean individual risks for each of the VOCs) ranged from $1.9 - 3.0 \times 10^{-2}$ for residents of New Jersey, and was 2.0×10^{-3} for residents of California. The additive 98th percentile individual risks were $4.6 - 4.8 \times 10^{-2}$ and 1.1×10^{-2}, respectively. The authors also presented additive mean individual risks for those 13 chemicals, discussed earlier, for which there is either animal bioassay data or human epidemiology data (3×10^{-3} in New Jersey and 1×10^{-3} in California).

McCann et al. (1986) presented several estimates of individual risks, based on mean or median levels monitored in indoor air, for each of 16 VOCs (including formaldehyde and the pesticide, lindane). Of these 16 chemicals, two (1,1-dichloroethane and ethanol) are not established as carcinogens by EPA. The unit risk estimates used in the assessment were obtained by: 1) use of the multistage procedure [for both MLEs and upper-bound (95%) risk estimates]; 2) use of the TD_{50}, as discussed previously, assuming linearity, and, where risks were reported to be non-linear, a less than or greater than sign, as appropriate; and 3) use of EPA (upper-bound) unit risk estimates. (Note: Some of the EPA unit risk estimates used by McCann are not current. For example, the estimate used for methylene chloride is an order of magnitude above current estimates.)

Exposures were estimated based on monitoring data from homes and public buildings, which were assembled as a base for a preliminary analysis only. The collection of data focused on measurements that reflected everyday exposure in normal (non-complaint) homes and offices. Because the data obtained were limited, the investigators stated that the averages cited could only be used with great uncertainty.

The additive mean individual risks (i.e., the sums of the individual risks for each of the 16 VOCs) ranged from 2.8×10^{-4} (multistage MLEs) to 9.8×10^{-3} (TD_{50}). The wide range is caused primarily by large variation in different estimates of the cancer risk posed by formaldehyde, which will be discussed further in the next section of this report. If formaldehyde risks are subtracted from the assessment, the additive mean individual risks for the remaining 15 VOCs ranges from 2.8×10^{-4} (multistage MLEs) to 1.5×10^{-3} (EPA unit risks).

Formaldehyde

Tancrede *et al.* (1987) estimated the individual risk from formaldehyde exposures in U.S. houses using rat bioassay data. The study design used was as described above for the VOC analysis. The author noted that the dose-response curve for nasal cancers in rats exhibits a strong upward curvature so that the risks at low doses may be overestimated. A unit risk estimate of 0.11 mg/kg-day (3.3×10^{-5}/ug/m^3) was calculated, similar to EPA's upper-bound unit risk estimate. A log-normal distribution with a median indoor concentration of 0.05 ppm (60 ug/m^3) from several studies in US homes were used to estimate exposures. Mean and 98th percentile lifetime risks of 3.4×10^{-2}

and 2.4 x 10^{-1} were estimated based on these data. The mean estimate is many orders of magnitude above the MLE and two orders of magnitude higher than the upper-bound estimate calculated by EPA based on exposures at the median, rather than mean, concentration.

McCann et al. **(1986)** also provided estimates of formaldehyde cancer risks from indoor air exposures. Four different methods were used to calculate risks, as discussed above for the VOCs. A 2600-fold variation in estimates of lifetime individual risk, from 3.7 x 10^{-6} (multistage MLE) to 9.5 x 10^{-3} (TD_{50}), were calculated by these investigators. They state that the variation observed is most likely due to the nonlinearity of the dose-response curve, which is reflected in the large difference in the multistage MLE and its upper-bound estimate (6.7 x 10^{-4}). (An even greater variation of 6 to 7 orders of magnitude between the MLE and upper-bound estimate is observed in the EPA analysis, presented earlier.)

Asbestos

Unit risk estimates for asbestos from sources other than EPA were summarized in EPA (1986d) and are presented in Exhibit 4-4. These estimates varied widely. Unit risk estimates for lung cancer from lifetime exposure to 0.01 fibers/ml ranged from 4 x 10^{-6} to 3 x 10^{-3}. Unit risk estimates for mesothelioma based on the same exposure ranged from 1.4 x 10^{-5} to 3 x 10^{-3}. In comparison, EPA unit risk estimates fall into the upper end of these ranges.

Following publication of the EPA (1986d) document, Breslow et al. (1986) revised the risk estimates of the National Academy of Sciences. These estimates, based on concentrations of 0.0004 and 0.002 fibers/ml and provided in Exhibit 4-5, are several-fold higher than the previous NAS estimates and two- to three-fold higher than the EPA estimates.

4.5 COMPARISON OF ESTIMATED INDOOR AIR RISKS TO OTHER ENVIRONMENTAl RISKS

EPA recently conducted a comparative study of environmental problems in the United States (EPA 1987d). Their report, although subjective and based on imperfect data, represented a credible first step toward a promising method of analyzing, developing, and implementing environmental policy. Based on this analysis, EPA concluded that indoor air pollution represents one of the most important environmental problems based on population risks. Four major types of effects were considered: cancer risks, non-cancer risks, ecological effects, and welfare effects. Thirty-one environmental problems in four broad categories were evaluated: indoor and outdoor air pollutants, water

Exhibit 4-4
Risks (x 10^{-6}) from Lifetime Asbestos Exposure to 0.01 Fibers/ml

Population	Lung Cancer	Mesothelioma
	NAS (1984)	
Female Smokers	575 (0-2,750)	225 (0-8,750)
Female Nonsmokers	75 (0-325)	225 (0-8,750)
Male Smokers	1,600 (0-7,250)	225 (0-8,750)
Male Nonsmokers	150 (0-550)	225 (0-8,750)
	CPSC (1983)	
Female Smokers	952 (301-3,012)	2,460 (780-7,799)
Female Nonsmokers	157 (50-4,960)	2,666 (843-8,429)
Male Smokers	1,550 (490-4,901)	1,742 (551-5,510)
Male Nonsmokers	175 (554-5,540)	2,153 (681-6,808)
	Ontario Royal Commission (1984)(1)	
Hypothetical workforce of 385 male smokers, 385 male nonsmokers, 115 female smokers, 115 female nonsmokers	4 - 760	14 - 1,875
	Advisory Committee on Asbestos (1979)(2)	
Males and females	86 - 2,860	
	Doll and Peto (1985)(3)	
Males	252	56

Source: EPA (1986d)

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[1] Exposure of 25 years from age 22.

[2] 50 years exposure.

[3] Exposure of 35 years from age 20.

Exhibit 4-5

NAS Revised Estimates of Risks from Lifetime Asbestos Exposures

Disease	Exposure Group	Estimated Lifetime Risk (x 10^{-6}) 0.0004 fibers/ml	 0.002 fiber/ml
Lung cancer	Male smoker	292	1459
	Female smoker	105	524
	Male nonsmoker	27	132
	Female nonsmoker	14	68
Mesothelioma	All groups	156	780

Source: Breslow et al. (1986)

contamination, toxic and hazardous waste, and exposure to pesticides and chemicals.

Risks from human exposures to environmental contaminants are generally less than many occupational health and safety risks in the mining and industrial environments. In addition, ecological and welfare losses for some environmental problems may dominate their public importance. Nevertheless, the population health risks posed by exposure to indoor air pollutants appear to be significantly greater than the health risks posed by some of the environmental problems that receive the most public concern and governmental funding, including hazardous and non-hazardous waste sites, and contaminated sludge. These risk rankings are very rough and are greatly limited by incomplete data, but the rankings demonstrate that, in relative terms, indoor air pollution is an important public health problem which merits more serious attention and study.

4.6 SUMMARY AND IMPLICATIONS

Except for radon, population risk estimates specific for indoor air pollutants have not been conducted by EPA. Nevertheless, the information available suggests that exposure to indoor air pollutants in nonindustrial environments poses a significant health threat to the domestic population. It appears that, in addition to radon, pollutants that pose significant cancer risk include ETS and VOCs. Radon and ETS are present in a very large number of residences, and ETS is present in office buildings. VOCs are ubiquitous in indoor environments. Additional cancer risks, not quantified here on a population basis, come from asbestos, formaldehyde, PAHs and pesticides in indoor air.

If diseases, such as heart disease and emphysema, were also considered, the mortality risks could increase significantly. In addition, the significant health burden associated with the known acute and non-fatal health effects described in Chapter 3 has not been quantified.

References

Advisory Committee on Asbestos. 1979. Asbestos Volume 1: Final Report of the Advisory Committee and Asbestos Volume 2: Papers Prepared for the Advisory Committee. Health and Safety Commission, London, as cited in EPA 1986d.

Arundel, A., Sterling, T., and Weinkam, J. 1987. Never Smoker Lung Cancer Risks from Exposure to Particulate Tobacco Smoke. Environ. Internat. 13: 409-426.

Breslow, L., et al., 1986. Response to letter on Risk from Exposure to Asbestos. Science 234:923.

Consumer Product Safety Commission (CPSC). 1983. Report to the U.S. Consumer Product Safety Commission by the Chronic Hazard Advisory Panel on Asbestos. Directorate for Health Sciences, as cited in EPA 1986d.

Doll, R., and Peto, J., 1985. Asbestos: Effects on Health of Exposure to Asbestos. Health and Safety Commission, London, as cited in EPA 1986d.

Environmental Protection Agency (EPA). September 24, 1986a. Guidelines for Carcinogenic Risk Assessment. 51 Federal Register 33994.

Environmental Protection Agency (EPA). September 24, 1986b. Guidelines for Estimating Exposures. 51 Federal Register 34042.

Environmental Protection Agency (EPA). December 1986c. Carcinogenicity Assessment of Chlordane and Heptachlor/Heptachlor Epoxide. Office of Research and Development.

Environmental Protection Agency (EPA). June 1986d. Airborne Asbestos Health Assessment Update. Office of Research and Development.

Environmental Protection Agency (EPA). September 1987a. Radon Reference Manual. Office of Radiation Programs.

Environmental Protection Agency (EPA). April 1987b. Assessment of Health Risks to Garment Workers and Certain Home Residents from Exposure to Formaldehyde. Office of Pesticides and Toxic Substances.

Environmental Protection Agency (EPA). August 1987c. Carcinogenicity Assessment of Aldrin and Dieldrin. Office of Research and Development.

Environmental Protection Agency (EPA). February 1987d. Unfinished Business: A Comparative Assessment of Environmental Problems. Office of Policy Analysis.

Environmental Protection Agency (EPA). June 1987e. EPA Indoor Air Quality Implementation Plan: Appendix A. Preliminary Indoor Air Pollution Information Assessment. Office of Research and Development.

Environmental Protection Agency (EPA). February 1988. Updated List of TSDF Health-based Constituents (from Hazardous Waste TSDF- Background Information for Proposed RCRA Air Emissions Standards, Volume II- Appendix E). Memorandum from A. A. Voorhees to S. R. Wyatt, Office of Air Quality Planning and Standards.

Hammond, C. 1966. Smoking in Relation to Death Rates of One Million Men and Women. Epidemiological Approaches to the Study of Cancer and Other Chronic Diseases, Haenszel, W., ed., NCI Monograph 19, pp. 127-204.

Kuller, L.H., et al., 1986. Environmental Health Persp. 70:57-69.

McCann, J., Horn, L., Girman, J., and Nero, A.V. October 1986. Potential Risks from Exposure to Organic Carcinogens in Indoor Air. Presented at the EPA Symposium in the Application of Short-term Bioassays in the Analysis of Complex Environmental Mixtures, Durham, NC.

Molhave, L. 1984. Volatile organic Compounds as Indoor Air Pollutants. Indoor Air and Human Health. Proceedings of the 7th Life Sciences symposium. Gammage, R. et al., eds. Knoxville, Tenn.

National Academy of Science (NAS). 1984. Asbestiform Fibers: Nonoccupational Health Risks, National Academy Press, as cited in EPA 1986d.

National Cancer Institute (NCI). 1987. 1986 Annual Cancer Statistics Review. NIH Publication No. 87-2789.

National Cancer Institute (NCI). June 1988. Personal communication.

National Council on Radiation Protection (NCRP). 1984. Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States. NCRP Report No. 78.

National Research Council (NRC). 1986. Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects. National Academy Press.

National Research Council (NRC). 1988. Health Risks of Radon and other Internally Deposited Alpha-Emitters (BEIR IV). National Academy Press.

NTP. August 17, 1984. Report of the NTP Ad Hoc Panel on Chemical Carcinogenesis Testing and Evaluation. U.S. Department of Health and Human Services.

OSTP. May 22, 1984. Chemical Carcinogen; Notice of Review of the Science and Its Associated Principles. 49 Federal Register 21594.

Ontario Royal Commission, 1984. Report of the Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario; V. 1-3. Ontario Ministry of the Attorney General, as cited in EPA 1986d.

Repace, J.L., and Lowrey, A.H. 1985a. A Quantitative Estimate of Nonsmokers' Lung Cancer Risk from Passive Smoking. Environ. Internat. 11:3-22.

Repace, J.L., and Lowrey, A. H., 1985b. An Indoor Air Quality Standard for Environmental Tobacco Smoke Based Upon Carcinogenic Risk. New York State J. Med. 85:381-383.

Repace, J.L., and Lowrey, A.H., 1986. A Rebuttal to Criticism of the Phenomenologic Model of Nonsmokers' Lung Cancer Risk from Passive Smoking. Environ. Carcino. Revs.(J. Environ. Sci. & Health) C4:225-235.

Repace, J.L., and Lowrey, A.H., 1987. Predicting the Lung Cancer Risk of Domestic Passive Smoking. American Rev. Resp. Dis. 136:1308.

Robins, James. 1986. Appendix D: Risk Assessment -- Exposure to Environmental Tobacco Smoke and Lung Cancer. NRC, Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects. National Academy Press.

Surgeon General, 1979. Smoking and Health. U.S. Dept. of Health, Education, and Welfare, Washington, DC.

Surgeon General, 1986. The Health Consequences of Involuntary Smoking. U.S. Dept. of Health & Human Services, Washington, DC.

Tancrede, M., Wilson, R., Zeise, L., and Crouch, E.A.C. 1987. The Carcinogenic Risk of Some Organic Vapors: A Theoretical Survey. Atmospheric Environment 21(10):2187-2205.

Wald, N.J., and Ritchie C. 1984. Validation of Studies on Lung Cancer in Nonsmokers Married to Smokers. Lancet 1: 1067.

Wald, N.J., et al., 1986. Does Breathing Other People's Smoke Cause Lung Cancer? British J. Med. 293:1217-1222.

Wallace, L.A. 1985. Cancer Risks from Organic Chemicals in the Home, in Proceedings: Environmental Risk Management: Is Analysis Useful? Air Pollution Control Association.

Wells, A.J. June 1986. Passive Smoking Mortality: A Review and Preliminary Risk Assessment. Presented at 79th annual meeting, Air Pollution Control Association, Minneapolis.

Wells, A.J. 1988. An Estimate of Adult Mortality in the United States from Passive Smoking. Environ. Internat. 14:in press.

CHAPTER 5 - ECONOMIC IMPACTS OF INDOOR AIR POLLUTION

This chapter discusses the economic costs imposed by indoor air pollution. The costs of both health effects and damages to equipment and materials are considered. The limited available evidence on indoor air pollution effects is used to develop estimates for selected types of costs. These cost estimates are incomplete and are subject to great uncertainty. However, the available evidence suggests that the costs imposed by indoor air pollution are very high. The costs of controlling indoor air pollution are not covered in this chapter.

The first section of this chapter discusses the nature of the economic effects of indoor air pollution. The second section describes methodologies for valuing economic effects, and the third section presents available estimates of economic costs and implications for business managers.

5.1 TYPES OF ECONOMIC COSTS

Three major types of economic costs are addressed in this chapter: (1) materials and equipment damages, (2) direct medical costs, and (3) lost productivity. These are defined as follows:

Materials and Equipment Damages

Indoor air pollution can soil indoor surfaces and can damage equipment and materials of various types.[1] The costs associated with equipment and materials damage include costs incurred to mitigate the effects of contamination (e.g. the costs of cleaning) and the costs of repair or premature replacement of equipment and materials.

Direct Medical Costs

People whose health is affected by poor indoor air quality may incur costs for medical services to alleviate the health effects. These medical costs include the costs of visits to the doctor or emergency room, hospital care, surgery, medication and the like.

Lost Productivity

Adverse health effects or general discomfort resulting from indoor air pollution may result in lost economic productivity. Lost productivity may occur on a continuum and include (1) lost productive years due to major illness, (2) lost time due to increased number of sick days taken from one's job, and (3) lost productive efficiency while on the job. All reduce the nation's capacity to product goods and services of value. Estimates of productivity should include the effects on both income earning and non-income earning activities of value. Activities such as child care in the home, homemaking, and learning activities in a school or university setting should be included, although often they are not because they are difficult to quantify.

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[1] Soiling refers to an effect that is reversible via cleaning, whereas materials damage is an irreversible effect.

Costs not Considered

These three categories of costs -- materials and equipment damage, direct medical costs, and lost productivity -- represent only a part of the total economic losses due to indoor air pollution. Some economic costs not included in the above categories are:

- other welfare loss associated with pain and suffering due to health effects that are not fully alleviated by medical treatment;
- the value of unpaid time spent by persons taking care of those whose health is affected in the home; and
- losses due to reduced enjoyment of recreational and other non-productive activities affected by indoor air pollution.

No attempt was made to estimate costs in these categories.

In addition, this report does not consider the effects of exposures to commercial or occupational sources of pollutants other than those occurring in white collar work environments. The categories of economic costs considered in this report therefore represent only a portion of the true losses to society resulting from poor indoor air quality.

5.2 METHODOLOGIES FOR CALCULATING ECONOMIC COSTS

A variety of approaches may be used to estimate the costs associated with indoor air pollution. These approaches have been described in a number of sources[2], and are only briefly summarized here.

Market-Based Measures

Economists generally prefer to use measures of costs based on people's actual behavior in response to pollution, as the best measure of the true economic costs. To the extent that observed market behavior can be used to assess costs, all effects of the pollution -- including such hard-to-measure effects as "pain and suffering" or reduction in the quality of life -- are included.

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[2] See, for example, Bentkover et al (1986); Freeman (1979) and Hartunian (1981).

Estimating costs due to indoor air pollution lends itself to use of market-based estimates in theory. The pollution is associated with specific buildings, and buildings are traded in real estate markets. Therefore, some of the costs of indoor air pollution can potentially be observed in reduced property values for buildings with air pollution problems.

EPA is not aware of any previous property value studies focusing on the effects of indoor air pollution. Such studies could eventually be useful. However, it is doubtful that they would provide reliable estimates of the true social costs of indoor air pollution at this time. People must be aware of problems with a building and must know that the problems are attributable to the building itself, before market behavior could accurately reflect the costs of indoor air pollution. Currently, there appears to be widespread ignorance about the sources and effects of indoor air pollution. Therefore, it is unlikely that current market values for buildings reflect the costs of indoor air pollution.

Contingent Valuation Measures

In the absence of market-based data on the effects of pollution, survey techniques are sometimes used to develop the equivalent of market valuations. These surveys seek respondents' views on their "willingness-to-pay" to reduce pollution -- in this case, to reduce their exposure to indoor air pollution.

There are difficult methodological problems with such surveys, but they have the virtue -- like market-based valuations -- of including all sources and types of welfare loss due to the pollution. EPA is not aware of any previous contingent valuation surveys designed to measure the costs of indoor air pollution.

Damage Function Measures

An alternative to using market-based data or contingent valuation measures is to develop estimates of the costs of individual end-effects of pollution, based on predictions of physical effects and use of various methods to value the effects. As described above, the drawback with the measurement of costs on an effect-by-effect basis is that it is limited to the effects that have been quantified. Quantifiable effects, plus welfare losses that are difficult to quantify inevitably are excluded. Therefore, summing the costs estimated for individual effects of pollution tends to understate the true social costs of pollution. However, this is the only approach available at this time to estimate the costs of indoor air pollution.

Two steps are involved in developing an effect-by-effect estimate of indoor air pollution costs. First, it is necessary to estimate "incidence" of each physical effect attributable to indoor air pollution -- e.g. numbers of cancer cases, levels of soiling, days of lost work, etc. Second, it is necessary to assign an economic value to those physical effects.

5.3 CALCULATING THE ECONOMIC COSTS OF INDOOR AIR POLLUTION

Available Data and Approach

In the absence of market-based or contingent valuation estimates of the costs of indoor air pollution, this report relies on damage function procedures to develop cost estimates.

Because of data limitations, it was not possible to develop quantitative estimates of the economic costs associated with equipment and materials damages caused by indoor air pollution, though these costs are discussed in the text.

For major illnesses, the pollutant-by-pollutant estimates of specific health effects along with estimates of the costs of those effects were used to estimate the economic costs of major illnesses resulting from indoor air pollution. Quantitative estimates of cases attributable to indoor air pollution for a limited number of pollutants and health effects were presented in Chapters 3 and 4. For those health effects quantified (cancer and coronary heart disease due to exposures to radon, volatile organic chemicals (VOCs) and environmental tobacco smoke (ETS)), predicted numbers of cases annually were multiplied by estimates of costs per case to provide national annual cost estimates. Two types of costs are calculated: (1) direct medical care costs for each type of case (doctor visits, hospitalization, medication, surgery, etc.), and (2) the present value of lost lifetime earnings per new case, including imputed earnings for homemaking activities. In addition, information from a study of emergency room visits for asthmatic children was used to estimate the costs of exposure to ETS for asthmatic children.

Because of data limitations, it was not feasible to develop reliable estimates of the economic cost of the increased number of sick days or of lost productivity while on the job, due to indoor air pollution. However, available surveys were used to provide information on these issues. While potential costs based on this data were calculated, these estimates are excluded from the final tabulations of economic costs because of uncertainties surrounding the data.

Economic Costs of Equipment and Materials Damage

Previous chapters of this report have focused primarily on the human health effects of indoor air pollution. High concentrations of contaminants in indoor air can also have adverse effects on materials and equipment. The effects of indoor air pollutants on indoor materials are influenced by a number of factors, including the type of pollutant, its concentration and exposure pattern, the type of material exposed, and other environmental factors. These effects are discussed in some detail in another report (EPA, 1987). Exhibit 5-1 taken from that report, summarizes the major materials damages according to the materials potentially at risk, the air pollutant(s) associated with the effect, and other environmental factors that can also contribute to materials damage. Microbial contamination, while potentially significant, is not included in this table.

The pollutants most often associated with these material damages include sulfur oxides (SOx), nitrogen oxides (NOx), ozone, particulates, and several acid gases (EPA, 1987). In addition, particulates in the form of water-soluble salts have been associated with damage to electronic equipment. Damages may include corrosion of electronic components and electrical current leakage, which may eventually result in equipment malfunction (EPA, 1987; Walker and Weschler, 1980). Finally, microbial contamination can result in significant damage to some materials.

The costs of materials and equipment damage by indoor air pollutants include the maintenance, repair, and/or replacement costs resulting from (1) soiling or deterioration of a material's appearance, or (2) reduced service life for corroded or degraded appliances, furnishings, and equipment. For example, if house textiles such as draperies fade or change color as a result of exposure to nitrogen oxide pollutants, then costs would consist of the cost of either repair or premature replacement of the draperies. In certain circumstances, such as in art museums or galleries, costs associated with installation of environmental controls such as air filtering systems may also be incurred.

Few damage functions have been developed for the effects of indoor air pollution on materials and equipment. Studies performed for EPA to support national ambient air quality standards (Manuel, 1981; 1983) provide household economic damage functions for soiling due to SO_2 and particulates. These studies rely on the results of several previous studies to estimate economic benefits due to reduced soiling, and might be applied to estimate the costs of indoor air particulate and SO_2 levels. However, the studies generally include categories of benefits (e.g. reduced washing of outside as well as inside window surfaces, cleaning of screens and storm windows, and

Exhibit 5-1
Air Pollution Effects on Materials

Materials	Type of Damage	Principal Air Pollutants	Other Environmental Factors
Metals	Corrosion, tarnishing	Sulfur oxides and other acid gases	Moisture, air, salt, microorganisms, particulate matter
Paint and organic coatings	Surface erosion, discoloration, soiling	Sulfur oxides, hydrogen sulfide, particulate matter	Moisture, sunlight, ozone, microorganisms
Textiles	Reduced tensile strength, soiling	Sulfur oxides, nitrogen oxides, particulate matter	Moisture, sunlight, ozone, physical wear
Textile dyes	Fading, color change	Nitrogen oxides, ozone	Sunlight
Paper	Embrittlement, soiling	Sulfur oxides, particulate matter	Moisture, physical wear
Magnetic storage media	Loss of signal	Particulate matter	Moisture, heat, wear
Photographic materials	Microblemishes, "sulfiding"	Sulfur oxides, hydrogen sulfide	Moisture, sunlight, heat, other acid gases, particulate matter, ozone and other oxidants
Rubber	Cracking	Ozone	Sunlight, physical wear
Leather	Weakening, powdered surface	Sulfur oxides	Physical wear
Ceramics	Changes surface appearance	Acid gases, HF	Moisture, microorganisms

Source: EPA, 1987.

cleaning of gutters) that are not relevant for estimating indoor air pollution costs. The studies also estimate benefits at concentrations well above those reported for indoors, and are based on 1972-1973 consumer expenditure data that are likely to be substantially out-of-date. For these reasons, the available soiling damage functions were not considered adequate to estimate soiling damages attributable to indoor air pollution.

Similarly, no quantitative estimates are available of the effects of indoor air pollution on equipment. Information from Dr. Charles Weschler of Bell Communications Research, however, provide examples of such damages that indicate that the costs may be high (Weschler, 1988). Telephone switching and computing equipment is susceptible to corrosion caused by air particles and gases. Weschler reported that the seven regional telephone companies have spent large sums to replace, clean or repair switches and other electronic equipment malfunctioning as a result of indoor air contaminants. Failures are known to have occurred throughout the system, and to range in cost from as little as $10,000 to as high as $380,000 per event. Bell Communications Research has developed guidelines for preventing such damages, including use of high efficiency filtration, constant use of fans, minimum air changes per hour, and keeping buildings pressurized to prevent infiltration of outdoor contaminants.

Various studies have also reported that home and office computing equipment and other electronic devices are subject to failure due to indoor air contamination (see, for example, Comizzoli _et al._, 1986). However, no estimates are available of the extent or costs of such damages.

In addition, it is known that microbial contamination can cause significant damage to buildings and equipment, and there is anecdotal evidence that damage can be so severe as to make a building unfit for human occupation. However, no quantitative data as to the extent of such damage is available.

Direct Medical Care Costs

Specific Major Illnesses

Available estimates of the annual number of health impairments resulting from indoor air pollution were presented in Chapters 3 and 4. Estimates of annual health impairments could be developed only for some of these health effects. To estimate the costs of medical expenditures associated with this subset of health effects, estimates of the present value of direct medical care costs per case were taken from Hartunian _et al._ (1981). These costs were developed for different types of illnesses from actual case experiences, and costs occurring in future years

Exhibit 5-2
Direct Medical Care Costs for Major Illness

Health Effect	Present Value of Medical Cost per New Case ($1986)
Lung Cancer	21,285
All Cancers	24,938
Coronary Heart Disease	9,684

Source: Hartunian et al. (1981) -- Hartunian values in 1975$ updated to 1986 dollars using an inflation factor for medical costs of 2.57 (1986 index of 433.5 divided by 1975 index of 168.6; index of medical care prices from U.S. Bureau of Labor Statistics. CPI Detailed Report.)

were discounted to develop present values. Present value costs calculated at a six percent discount rate were used in this report.

Exhibit 5-2 presents these costs per case taken from the Hartunian study. The average costs per case for all cancers and for coronary heart disease (CHD) were developed in the Hartunian study by weighting costs per case for different types of cancer or CHD by the relative prevalence of each type in 1975. The Hartunian estimates were inflated to 1986 dollars for use in this study.

Exhibit 5-3 presents estimates of the annual national costs of medical care resulting from the major indoor air pollution health effects identified in Chapters 3 and 4. As shown, estimated costs are over $1 billion annually. The range of cost estimates reflects estimates of numbers of cases annually from different sources reported in Chapters 3 and 4. Cancer cases due to exposure to VOCs, radon, and ETS account for the largest portion of estimated costs.

These estimates do not include the costs of many potential major illnesses and indoor air pollutants presented in Chapters 3 and 4, due to the limited quantitation of health impacts for these pollutants. For example, quantified national health

Exhibit 5-3
Annual Direct Medical Costs of Major Illness
($1986)

Source	New Cases/ Year	Cost/Case	Total Cost ($Millions)
	CANCER		
Radon	20,000 (Lung)	$21,285	$426
ETS	12-5,000 (Lung)	$21,285	$0.26-111
	11,000 (Other)	$24,938	$274
Six VOCs	1,000-5,000 (Other)	$24,938	$25-125
Total Cancer Costs			**$725-936**
	NON-CANCER		
ETS	32,000 (Heart Disease)	$9,684	$290
Total Medical Costs			**$1,015-1,226**

Source: Section 3.3, and Exhibits 4-1, 4-3, and 5-2.

Note: Except for radon, risk estimates have not been critically evaluated for their strengths and weaknesses in addressing a quantitative analysis of the level of risk from indoor air pollutants. Therefore, EPA does not necessarily agree with the study designs used or with the conclusions reached by the authors of these assessments. See footnote to Exhibit 4-3.

Exhibit 5-4
Costs of Additional Emergency Room Visits for Asthmatic Children in Households with Smokers

Increased number of emergency room visits per year, asthmatic children in smoking vs. non-smoking households:	1.26[a]
Estimated cost of additional visits per year:	$92[a]
Estimated percent of children in smoking households:	43-62%[b]
Estimated percent of population that are asthmatic:	
o total population	4.0%[c]
o ratio of prevalence in children to prevalence in the total population	1.25[d]
o estimated percent of children that are asthmatic (1.25 X 5)	5.0%
Number of children in the United States under 18 (1985):	63 M[e]
National annual cost of additional emergency room visits for asthmatic children in smoking households:	$157-226 M[f]

a. Evans et al. (1987).
b. 43% from CDC (1986). 62% from Bonham and Wilson (1981) as cited in Repace and Lowrey (1985).
c. Chapter 3, Exhibit 3-2.
d. National Center for Health Statistics, private communication, 1988.
e. U. S. Census Bureau, Current Population Reports
f. 1.26 * 92 * (0.43-0.62) * 0.05 * 63

impacts are not available for indoor exposures to pesticides, asbestos, formaldehyde or many types of VOCs, nor are estimates available for number of cases of emphysema, or other illnesses due to ETS exposure.

Effect of ETS of Asthmatic Children

A recent study of 237 children from low-income families in New York City (Evans et al., 1987) found that asthmatic childrenfrom smoking households visited emergency rooms more often on average than did asthmatic children from non-smoking households. Children from smoking households averaged 3.09 emergency room visits per year compared with 1.83 times per year for children from non-smoking households. Exhibit 5-4 presents a calculation of aggregate national costs due to increased emergency room visits for asthmatic children due to ETS in the home, based on this study. The costs are estimated to total between $157 and $226 million per year.

Employee Sick Days

Little data exists on the number of employee sick days or on the productivity lost because of poor indoor air quality. However, some survey studies have been conducted. The problems with these studies are twofold. First, it is difficult for an employee to causally link a health effect to poor indoor air quality. Second, it is not known if the buildings from some of these studies represent the general building population.

One survey of office workers conducted by Honeywell (Honeywell, 1985) found that 19 percent of respondents (115 of 600) often or sometimes had difficulty doing their work because of office air quality. Of the 155, 64 (or 11 percent of all respondents) reported that a "tired/sleepy feeling" was a "very serious" or "somewhat serious" problem because of office air quality. Similarly, 52 (nine percent of all respondents) cited a "congested nose," 47 (eight percent) cited "eye irritation," and 46 (eight percent) cited "difficulty breathing" as being "very serious" or "somewhat serious" problems.

However, while the Honeywell survey was scientifically administered, it does not provide sufficient information for quantifying economic costs.

In addition to the Honeywell survey, a recent survey of 94 state government office buildings was conducted by a coalition of employee unions in the New England states of Maine and New Hampshire during the summer of 1987. The survey sought information on the extent and effects of poor indoor air quality, including the losses in productivity, the increased number of sick days, and the frequency of doctors visits, attributed by respondents to poor indoor air quality.

The New England survey results report large numbers of complaints about health symptoms that respondents attribute to poor air quality: 30 percent of all respondents reported having headaches, 44 percent reported fatigue or drowsiness, 37 percent reported eye strain, and 69 percent reported some loss in productivity on a daily or weekly basis due to poor indoor air quality.

The kind of information provided in the New England survey is useful for estimating three elements of economic cost -- direct medical cost of increased doctors visits, the economic cost of lost productivity from increased sick days, and the economic cost of lower productivity while on the job. However, the New England survey was not scientifically administered and may have significant biases.

While the Honeywell survey and the New England survey are not directly comparable, the prevalence rates in the New England survey appear to be three to four times higher than those reported in the Honeywell survey. However, other data suggest that prevalence rates of the New England survey may not be far from the norm. For example, in a major British study (Wilson and Hedge, 1987), prevalence rates of work related symptoms were: lethargy (57%), headache (43%), stuffy nose (47%), and itchy eyes (27%). In addition, 24% of the respondents thought that their work environment decreased their productivity by 20% or more, 59% thought it had little or no effect, and 16% thought it increased their productivity. Likewise, in a major study of Danish Town Halls (Skov and Valbjorn, 1987) and other buildings, approximate prevalence rates of work related symptoms were fatigue (28%), headaches (20%), eye irritation (13%), and nasal irritation (18%).

In order to obtain at least a qualitative estimate of the economic costs from medical visits, sick days lost, and productivity losses, some adjustments were made to the New England survey data, and conservative assumptions concerning those not responding were incorporated into the analysis.[3] The adjusted survey results show that an average of 0.24 doctor visits per worker per year were attributable to poor indoor air quality. If this figure were applied to the nation's 64 million white collar work force (BLS, 1988), and an average cost of $30 is assumed for a medical visit to a doctor or medical practitioner, national medical care costs for doctors visits (other than for major medical illness) of white collar workers due to indoor air pollution would be on the order of half a billion dollars per year.

Economic Cost of Productivity Losses

Loss of Earnings Due to Major Illnesses

Exhibit 5-5 shows estimates of the present value of lost lifetime work output for three types of major health effects. These estimates are taken from Hartunian, 1981 and include an imputed value for homemaking activities. The Hartunian values have been updated to 1986 dollars and inflated by 37 percent to reflect the value of fringe benefits for all private industry employers (Nathan, 1987). These costs per case are the present value of present and future lost worktime due to a new case of cancer or CHD, with future years' values discounted at six percent.

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[3] Excluded from the data were responses indicating more than 6 doctor visits per year, more than 12 days of sick leave, or more than 30 percent productivity loss due to indoor air pollution. In addition, it was assumed that no effects of indoor air pollution were experienced by those not receiving the survey, and those who received the survey but did not respond.

Exhibit 5-5
Productivity Costs of Major Illness
(Cost per Case)

Health Effect	Present Value of Lost Earnings Per Case ($1986)
Lung Cancer	99,532
All Cancers	92,645
Coronary Heart Disease	44,896

Source: Hartunian, et al. (1981) -- Hartunian values in 1975 dollars updated to 1986 dollars using the ratio of the 1986 to the 1975 GNP price deflators (114.1/59.3 = 1.92; U.S. Department of Commerce, Statistical Abstract of the United States, 1988, p. 252), and inflated by 37 percent to reflect the added value of fringe benefits (Nathan, 1987).

Exhibit 5-6 shows the calculation of the national annual cost of productivity losses associated with major illnesses caused by indoor air pollution. This calculation uses the same approach as the calculation of direct medical costs in Exhibit 5-3. The estimated cost ranges from $4.7 billion to $5.4 billion for new cases caused by indoor pollution annually.

Productivity Loss While on the Job and from Increased Sick Days

Productivity losses on the job due to indoor air pollution may take several forms. For example, workers may be less effective with their work because they feel fatigued, or suffer from headaches, eye irritation or other effects. These are typical symptoms of sick building syndrome. Workers may therefore accomplish less per hour worked or may spend more time away from their work location -- e.g. taking breaks or walks outdoors to avoid poor air quality where they work. These effects will result in lower output per hour at work. In addition, workers may be out sick more often.

The value of both reduced output while at work and increased sick leave time lost from work can be measured by multiplying average hours of productive work lost by an average hourly

Exhibit 5-6
Annual Productivity Costs of Major Illnesses
($1986)

Source	New Cases/ Year	Cost/Case	Total Cost ($Millions)
		CANCER	
Radon	20,000 (Lung)	$99,532	$1,991
ETS	12-5000 (Lung)	$99,532	$1.2-518
	11,000 (Other)	$92,645	$1,019
VOCs	1,000-5,000 (Other)	$92,645	$93-463
		Total Cancer	$3,011-3,991
		NON-CANCER	
ETS	32,000 (Heart Disease)	$44,896	$1,437
Total Cancer and Non-Cancer			**$4,448-5,428**

Source: Section 3.3 and Exhibits 4-1, 4-3 and 5-5.

Note: Except for radon, risk estimates have not been critically evaluated for their strengths and weaknesses in addressing a quantitative analysis of the level of risk from indoor air pollutants. Therefore, EPA does not necessarily agree with the study designs used or with the conclusions reached by the authors of these assessments. See footnote to Exhibit 4-3.

compensation rate. The average total compensation rate per hour worked for white collar workers is $15.56. This rate includes benefits such as paid leave, premium pay for overtime, insurance and retirement benefits, and legally required benefits such as Social Security (Nathan, 1987).

Data from the New England survey, which was adjusted as previously indicated, would attribute an average productivity loss of 3% to poor indoor air quality. This is equivalent to approximately 14 minutes per day in lost work time. Respondents would also attribute an average of 0.6 added sick days per year to poor indoor air quality. If these results were applied to the nation's white collar labor force, the economic cost to the nation would be in the order of $60 billion annually. While this can not be regarded as a reliable estimate, it suggests quite strongly that productivity losses may be in the order of tens of billions of dollars per year.

Implications for Business Managers

Many efforts to improve indoor air quality in office environments can be administered at little or no cost. These include, for example, proper storage of toxic cleaning and maintenance products, and basic maintenance of the ventilation system. Nevertheless, some buildings may require actions which increase energy or other operation or maintenance costs, and for this reason they are often resisted. But, we have seen that poor indoor air quality increases labor costs through losses in productivity, increased employee sick days, and medical costs. This suggests that measures to cut building construction and operating costs may increase the total cost to business because of a higher wage bill, and that money spent to improve indoor air quality may be profitable from a purely business profit and loss standpoint.

It is useful to ask whether costs incurred to improve indoor air quality would pay for themselves in increased productivity. Labor costs in a typical office setting will depend on salary levels and occupant densities. Typical labor costs are on the order of $100 to $300 per square foot per year.[4] (Dorgan, 1988; Woods _et al._, 1987). In comparison, energy costs are on the order of only $1 or $2 per square foot per year, while total environmental control costs (energy, operation and maintenance) are on the order of $2 to $10 per square foot per year. (Dorgan, 1988; Woods _et al._, 1987, Eto and Meyer, 1988). It is clear, therefore, that from a profit and loss standpoint, productivity, not energy consumption, is the dominant consideration for office environments.

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[4] For example, ASHRAE standard 62-1981 assumes an occupant density amounting to about 150 square feet per person in office environments. With a labor cost rate of $15.56 per hour and a yearly work rate of 2000 hours per year, labor cost for office environments would be $207 per square foot per year.

While cost increases to improve indoor air quality could be substantial in absolute dollar terms, Exhibit 5-7 demonstrates that such costs would be more than offset by very modest productivity increases. For example, a 5.0 percent increase in energy costs (or a 1.67 percent increase in total environmental control costs), would require only a 0.025 to 0.05 percent increase in productivity to make this a worthwhile expense. A 50 percent increase in energy costs (or a 16.67 percent increase in total environmental control cost) would require only a 0.25 to 0.50 percent increase in productivity. This result suggests that expenditures for improved indoor air quality could generate exceedingly high returns to the business community, where labor is an important cost category, and where the building community is unaware or has neglected to implement this potential productivity gain.

Exhibit 5-7
Productivity Gains Necessary to Offset Operating Cost Increases

Cost Increases Energy	Cost Increases or Total Env.	Offsetting Productivity Gain
5 %	1.67 %	0.05 %
15 %	5.00 %	0.15 %
25 %	8.33 %	0.25 %
50 %	16.67 %	0.50 %

Base cost assumptions:
Energy costs = $2 per sq. ft. per yr.
Labor costs = $200 per sq. ft. per yr.
Total Environmental costs = $6 per sq. ft. per yr.

Increasing ventilation capacity from 5 to 20 cfm per occupant is estimated to increase total construction costs less than $0.50 per sq. ft. under typical circumstances (Eto and Meyer, 1988). However, for existing buildings, significant retrofit costs may be required to increase ventilation, improve air distribution, or to otherwise improve indoor air quality. It is useful to ask, therefore, whether productivity gains could be expected to offset capital expenditures either for new construction or for retrofit applications. Productivity gains needed to offset alternative capital expenditure requirements, with and without a modest (15 percent) increase in energy operating costs, are displayed in Exhibit 5-8. For example, a capital expenditure of $15 per square foot would require about 1 percent increase in productivity to offset the expenditure. If, in addition, energy operating costs were increased 15 percent, productivity would have to increase by 1.14 percent. Given the dominance of labor costs, even a modest increase in productivity could justify substantial capital expenditures to improve indoor air quality.

Exhibit 5-8
Productivity Gains Necessary to Offset Capital Expenditures

Capital Cost ($/sq.ft)	Annualized Cost ($/sq. ft)	Offsetting Productivity Gains No Change in Operating Cost	Offsetting Productivity Gains Operating Cost Increase by 15%
1	0.13	0.07 %	0.22 %
5	0.66	0.33 %	0.48 %
10	1.31	0.66 %	0.81 %
15	1.97	0.99 %	1.14 %
25	3.29	1.64 %	1.80 %
50	6.57	3.29 %	3.44 %

Base cost assumptions:
Energy costs = $2 per sq. ft. per yr.
Annualized costs are capital costs amortized at 10% over a 15-year life.

5.4 SUMMARY AND CONCLUSIONS

Exhibit 5-9 summarizes the estimates developed in this chapter of the economic costs attributable to indoor air pollution. As shown in the exhibit, cost estimates are available only for a limited set of potential indoor air pollution effects. The reported costs were developed by extrapolating from limited evidence. Substantial additional basic research and analysis will be required to improve on these estimates of economic costs.

Despite the limitations in the available evidence, the calculations presented in this chapter suggest that the costs of indoor air pollution are very high. Many costs of indoor air pollution have not been calculated. Nevertheless, because of the large numbers of people and buildings potentially affected, as well as the wide range of effects for which there is an economic cost component, it is reasonable to conclude the aggregate costs of indoor air pollution amount to tens of billions of dollars per year.

Of the costs shown in Exhibit 5-9, ETS accounts for a large portion of the costs attributed to specific sources (cancer, heart disease, and effects on asthmatic children). Not displayed in Exhibit 5-9 because of data limitations are specific estimates of the economic costs associated with losses in productivity and increases in employee sick days from unspecified sources typified by the sick building syndrome. As indicated in

Exhibit 5-9
Summary of Annual Economic Costs of Indoor Air Pollution
($ millions)

Pollutant	Direct Medical Expenditures		Lost Productivity	Materials and Equip. Damage	Total Calculated Costs[1]
	Cancer	Non-Cancer			
Radon and radon daughters	$426	NC	$1,991		$2,417
ETS	$274-385	$447-516	$2,457-2,974	NC	$3,178-3,875
Biological contaminants	NC	NC	NC		NC
VOCs					
6 VOCs	$25-125	NC	$93-463		$118-588
Other VOCs	NC	NC	NC		NC
Asbestos	NC	NC	NC		NC
Combustion gases	NC	NC	NC	NC	NC
Particulate matter	NC	NC	NC	NC	NC
Unspecified (sick building syndrome)	NC	(see text)	(see text)		(see text)

NC - Costs not calculated

1. Includes only costs associated with those types of cancer and other health effects for which estimates of numbers of annual health impairments were calculated in Chapters 3 and 4. The estimated costs shown here are therefore understated.

Source: Exhibits 5-3, 5-4, and 5-6.

the text, these costs may be on the order of tens of billions of dollars per year.

Subsequent chapters will discuss methods that can be used to improve indoor air quality. In some cases, the costs of changes needed to correct poor indoor air quality will be high. This chapter suggests, however, that the costs imposed by continuing to live with poor indoor air conditions are also very high, and for business establishments where labor is an important cost factor, remedial actions are likely to be cost effective, even if they require expensive retrofit. Over time, development and dissemination of information on the costs of poor indoor air may encourage building owners to upgrade the quality of indoor air to prevent decreases in the value of their buildings as tenants and clients become more knowledgeable about the effects of indoor air contamination.

References

American Society of Hating, Refrigeration, and Air-Conditioning Engineers ASHRAE. 1986. ASHRAE Proposed American National Standard: Ventilation for Acceptable Indoor Air Quality, Public Review Draft, ASHRAE 62-1981R.

Bentkover, J. et al. 1986. Benefits Assessment: The State of the Art. D. Reidel Publishing Co.

Bonham, G.S. and Wilson, R.W. (1981). Children's Health in Families with Cigarette Smokers. Amer. J. Public Health 71, 290-293.

Bureau of the Census. 1986. Statistical Abstract of the United States: 1987.

Comizzoli, R.B., et al. 1986. Corrosion of Electronic Materials and Devices. Science, 17 October, 1986.

Dorgan, C. E. 1988. Advanced Control Concepts Related to Comfort, Indoor Air Quality, and Productivity. Engineering Solutions to Indoor Air Problems; Proceedings of the ASHRAE Conference, IAQ 88, Atlanta GA.

Environmental Protection Agency (EPA). 1987. EPA Indoor Air Quality Implementation Plan, Appendix A.

Eto, Joseph H, and Meyer, Cecile. 1988. The HVAC Costs of Fresh Air Ventilation in Office Buildings. ASHRAE Transactions, V 94 (II).

Evans, D., et al. 1987. The Impact of Passive Smoking on Emergency Room Visits of Urban Children with Asthma. American review of Respiratory Diseases, 135:567-572; summarized in Residential Hygiene, Vol. 4, No. 2. p. 12.

Freeman, A.M. 1979. The Benefits of Environmental Improvement, Johns Hopkins University Press.

Hartunian, N. et al. 1981. The Incidence and Economic Costs of Major Health Impairments. Lexington Books.

Honeywell Techanalysis. 1985. Indoor Air Quality: A National Survey of Office Worker Attitudes. Minneapolis, MN.

Manuel, E.H. et al. 1983. Benefits and Net Benefit Analysis of Alternative National Ambient Air Quality Standards for Particulate Matter. Report for Office of Air Quality Planning and Standards, U.S. EPA.

Nathan, F. 1987. Analyzing Employer's cost for Wages, Salaries, and Benefits. Monthly Labor Review, October 1987, pp. 3 ff.

National Center for Health Statistics. 1986. National Health Survey, Series 10, No. 164.

Repace, J.L. and Lowrey, A.H. 1985. A Quantitative Estimate of Nonsmokers' Lung Cancer Risk from Passive Smoking. Environment International, Vol. 11.

Skov, P. and Valbjorn, O., 1987. "The "Sick" Building Syndrome in the Office Environment: The Danish Town Hall Study. Environment International, vol. 13-339-349.

U.S. Department of Labor. Bureau of Labor Statistics (BLS). 1988. Employment and Earnings, June.

Walker, M. and Weschler, C. 1980. Water-Soluble Components of Size-Fractionated Aerosols Collected After Hours in a Modern Office Building. Environ. Sci. Technol. 14:594-597.

Weschler, C. 1988. Bell Communications Research. Personal Communication with David Mudarri, EPA, June 30, 1988.

Wilson, S., and Hedge, A., 1987. The Office Environment Survey: A Study of Building Sickness. A study sponsored by the Health Promotion Research Trust, Building Use Studies, Ltd., London.

Woods, J.E., et al. 1987. Relationships Between Building Energy Management and Indoor Air Quality: Perceptions of Conflict and Opportunity in the United States and Europe. Proceedings of the Third International Congress on Building Energy Management, Presses Polytechniques Romandes, Lausanne, Switzerland.

PART II

Controlling Indoor Air Pollution

CHAPTER 6 - METHODS AND STRATEGIES OF CONTROL

This chapter discusses strategies for controlling indoor air quality. In the first section we present engineering and operational control strategies to mitigate or prevent indoor air problems. The second section addresses the importance of appropriate building design and maintenance in controlling indoor air pollution. In the third section we introduce protocols to diagnose air quality problems as a critical first step in effective indoor air problem mitigation and prevention. Finally, in the fourth section we present options for the administrative control of indoor air quality.

6.1 ENGINEERING AND OPERATIONAL CONTROL STRATEGIES

Engineering control of indoor air pollution relies on three general processes: (1) source control, (2) ventilation control, and (3) air cleaning. Source control improves indoor air quality by directly reducing the contribution of sources to indoor air pollutant levels. Ventilation control, in contrast, dilutes indoor air with outdoor air to reduce concentrations of indoor pollutants. Finally, air cleaning controls indoor air pollution by actively removing pollutants from the indoor air through chemical and physical methods. This section introduces the principles involved in each of these control strategies and the range of indoor air concerns to which they can be successfully applied.

Source Control

Combustion appliances, tobacco smoking, building materials, soil gas, commercial and consumer products, and microbial growth potentially generate indoor air pollutants, and emissions from these sources can be controlled to reduce indoor air quality concerns. Source control strategies fall into four categories: (1) source substitution and/or removal; (2) source encapsulation and/or confinement; (3) proper source operation and maintenance; and (4) source modification.

Removing indoor pollutant sources from the indoor environment and replacing them with non-polluting substitutes can directly and substantially improve indoor air quality. Successful use of this strategy requires sacrificing the function of source materials or finding suitable substitutes. Therefore, decisions to remove and substitute for pollutant sources require a careful balancing of economic, functional, and health concerns.

Some sources of indoor air pollution that cannot be easily removed or replaced can be controlled by encapsulation or confinement. These processes do not eliminate potential pollution sources, but rather restrict the movement of the pollutants of concern in the indoor atmosphere.

Properly operating and maintaining appliances and products can also reduce their emissions of indoor air pollutants. This control strategy can include tuning or cleaning sources to reduce pollutant generation or curtailing source use or shifting source use in time and space in order to separate emissions from human activity and thereby reduce human exposure.

Many product-related sources of indoor air pollutants can be modified to reduce their contaminant emissions. Some of these modifications can be carried out by the manufacturer while others may take place at the location of source use.

Source control for combustion appliances, tobacco smoking, building materials, consumer and commercial products, biological sources and radon are discussed below.

Combustion Appliances

Pollutant emissions from combustion appliances can be controlled through exhaust ventilation, confinement, proper operation and maintenance, and burner modification.

Combustion pollutants can be controlled by venting flue gases. Confining combustion appliances to specially partitioned rooms or compartments prevents them from polluting the larger, general-use habitable space. In addition, combustion appliances burn more cleanly (i.e., emit reduced quantities of pollutants) if kept properly adjusted and cleaned through appropriate maintenance.

A number of manufacturer modifications to combustion appliances have resulted in cleaner emissions. Advances in gas burner technology may improve appliance performance by reducing the rate of pollutant formation. For example, tests have shown that inserts for burners in gas ranges, ovens, and other appliances reduce emissions of combustion gases and particulates (DeWerth and Kurzynske, 1986). Also, replacing pilot lights with electronic ignition for gas burners eliminates the continuous low-level emission of combustion products from the gas pilot (Fisk _et al_., 1985). Inserts in fireplaces and air-tight stoves have improved the combustion performance of, and reduced the leakage of, combustion products from these appliances into the indoor air (Fisk _et al_., 1985).

Tobacco Smoking

ETS can be controlled by removing its source, tobacco smoking, from indoor environments or confining tobacco smoking to designated spaces apart from general habitable areas. Effective control of ETS by source confinement requires that designated smoking areas be depressurized and vented directly to the outside. Smoking restrictions have been most widely applied to public buildings and public areas of buildings, but are becoming increasingly used in private spaces.

Building Materials

Control of pollutant emissions from building materials can be accomplished through replacement or substitution, confinement, or modification of problem materials.

Many building materials emit indoor air pollutants. Examples of those which can be replaced in building construction or renovation include pressed wood products and foam insulation (formaldehyde), bricks and concrete (radon), and asbestos and glass fiber products. Urea-formaldehyde foam insulation and pressed wood products may have superior durability, economic, and structural qualities compared to their available substitutes. Consequently, it may be desirable to reduce emission rates from these materials through product modifications (Fisk et al., 1985). However, high-radium building products can be replaced with similar products with less potential to emit radon, and substitutes for most uses of asbestos in building materials have been found. Asbestos-containing building materials are no longer used in new construction. [Removing asbestos from existing buildings can produce high concentrations of airborne asbestos and requires efforts to limit exposures to airborne fibers during and after removal activities (D'Angelo et al., 1987). Asbestos should only be removed by experts using EPA approved methods.

Encapsulation of building materials is said to reduce pollutant release from the source material to the indoor air. However, only rudimentary information is available on the effects of encapsulation. Formaldehyde emissions were reported to have been significantly reduced by covering pressed wood products with linoleum (Matthews, et al. 1986) or with sealants and varnishes (Godish and Rouch, 1987). Encapsulation is also reported to have been effective in reducing pentachlorophenol emissions from wood products treated with this pesticide (Levin and Hahn, 1984).

Manufacturers may also modify their product to reduce emissions, as, for example, in changing the resin content of pressed wood products, or curing their products prior to sale.

Consumer and Commercial Products

Products such as furnishings, carpets, paints, wall coverings, pesticides, cleaners, and personal care products contain a variety of potential air pollutants. Controlling indoor air pollution from these products can be accomplished by substituting non-polluting products, properly using and maintaining potential problem products, or modifying product composition to mitigate potential indoor air concerns.

Discontinuing or curtailing the use of products that emit air pollutants would reduce associated pollutant concentrations in the indoor environment, but would, in many cases, require the provision of acceptable substitutes or, at least, the adoption of alternative practices (e.g., better general hygiene and less dependence on aerosol room air fresheners).

Altering the timing and location of product use can reduce human exposure to pollutants without necessarily reducing concentrations. Some products (e.g. household pesticides, furniture strippers) will necessarily produce air pollution, but altering use patterns can help separate pollutants from human activity.

The replacement of lead-based paints and the decreased use of aerosol-propelled personal comfort products illustrate the use of source substitution to control consumer product-related pollution problems. As an indication of the potential for continued progress in this area, Levin (1987a) reported that a manufacturer modified a shelving product by enclosing its particleboard core in response to indoor air quality concerns.

Biological Sources

General hygiene can control the proliferation of biological agents such as dust mites and bacterial and fungal growth, particularly in areas which can act as growth media for such sources. Regularly changing filters in ventilation systems, cleaning humidifiers and air conditioners, and disposing of water damaged rugs and furnishings will help control biological agents.

Morey, et al. (1984b) provides the following recommendations to prevent contamination: (1) prevent moisture incursion into occupied spaces and HVAC system components, (2) remove stagnant water and slimes from building mechanical ventilation systems, (3) use steam as a moisture source in humidifiers, (4) eliminate water sprays as components of office building HVAC systems, (5) maintain relative humidity below 70%, (6) use filters with 50-70% rated efficiency, (7) remove water-damaged material and furnishings, and (8) provide a fastidious maintenance program for HVAC air handling and fan coil units.

Radon Infiltration

Outside sources of radon can be controlled by a number of source control methods. Sealing cracks and seams in slabs, basement walls, and floors can restrict or eliminate radon infiltration into the indoor air (EPA, 1987), though it is not always effective. The technique may work better in some buildings than others, and is often combined with subslab ventilation. Radon infiltration has also been controlled by ventilating and pressurizing basements and by applying suction to drain tiles or the area beneath building slabs in order to redirect radon laden soil gas away from the indoor environment (Henschel and Scott, 1987; Ericson et al., 1984).

Ventilation Control

A common method of controlling the quality of indoor air uses outside air to dilute indoor concentrations of air pollutants. This approach to indoor air quality control relies on a relatively clean outside atmosphere and mechanisms to exchange air between the inside and outside of a building system and to distribute outdoor air throughout the building. The following paragraphs discuss indoor air quality control by general and specific ventilation strategies.

General Ventilation

Incorporating outdoor air into the indoor environment has been a component of building design and operation for thousands of years. Indoor environments, except for the extreme cases of spacecraft and submarines, are not isolated from their surroundings and use outside air to revitalize indoor air. Since ventilation replaces indoor air with outdoor air, this control strategy effectively dilutes and removes indoor airborne contaminants at a rate dependent on the effective rate of ventilation and outdoor pollutant concentrations.

Ventilation requirements, such as those incorporated in ASHRAE Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality," are intended to control the products of human metabolism and other contaminants under most circumstances. However, source control, air cleaning, and increased ventilation may also be required in the presence of strong sources. The ASHRAE requirements, as discussed in a subsequent chapter, prescribe minimum outdoor air ventilation rates to be provided by properly designed systems. The specified rates are based on the assumption of complete mixing of outdoor air throughout the indoor atmosphere (ASHRAE, 1981). The ventilation rates are specific to building type and usage. A recent proposed revision to the ventilation standard (ASHRAE 62-1981R) specifies a minimum ventilation rate of twenty cubic feet per minute (cfm) per person for office environments (ASHRAE, 1986).

It has become common in recent years, with rising energy costs, to decrease ventilation rates to conserve energy. The use of variable air volume ventilation systems can reduce energy costs arising from conditioning outside air, but such systems may not maintain exchange rates protective of indoor air quality (ASHRAE, 1986; Guttman, 1987). Indoor air quality problems in a number of office buildings have been related to inadequate ventilation and were remedied by retrofitting HVAC systems. It is important to reiterate, however, that adequate ventilation in accordance with ASHRAE 62-1981R does not guarantee acceptable indoor air quality; many indoor air quality problems require some form of source control in addition to better ventilation, and, for problems such as radon, some forms of ventilation may actually exacerbate the problem.

Local or Exhaust Ventilation

A specific method of using ventilation to control indoor air quality is local ventilation in the vicinity of pollutant sources. Local ventilation, also called exhaust ventilation, typically involves providing a separate exhaust system for a plume of contaminants from a pollutant source. This strategy decreases source strength and removes indoor air contaminants before they are dispersed throughout the indoor air (Bearg and Turner, 1987). In this regard local ventilation can be thought of as a source control strategy.

Local ventilation is often combined with the use of pressure differentials to contain contaminants within specific negative pressure areas. This technique is used routinely in sensitive health-care microenvironments and has been applied to the asbestos removal process to contain the pollutant within the working area (D'Angelo et al., 1987), and is regularly used for exhausting toilet facilities and preventing contaminants from entering other parts of the building.

Demand-Induced Ventilation

A sensor may be used to trigger increased outdoor ventilation rates when levels of some specified contaminant reach or exceed a specified level. This technique attempts to balance the need for adequate indoor air quality, thermal comfort, and energy conservation by integrating indoor contaminant and temperature levels within the same control mechanism.

A carbon dioxide (CO_2) sensor has been suggested for use in general office environments (Vaculik, 1987; Fecker et al., 1987). However, other pollutants may also be used, singly or in combination, depending on the circumstances. In a demonstration of air quality control using this strategy, for example, an office building air quality problem caused by a parking structure was corrected, in part, by a carbon monoxide sensor used to increase ventilation rates when CO levels from the garage reached a preset threshold (Boelter and Monaco, 1987).

Ventilation Effectiveness (Efficiency)

The extent to which ventilation air reaches the breathing zone of building occupants is termed ventilation effectiveness or ventilation efficiency. ASHRAE ventilation standards assume that ventilated air is perfectly mixed into the occupied zone. In the event that complete mixing does not occur, ventilation control of contaminants is compromised, and readjustment of the HVAC system or implementation of some other operational control strategy becomes necessary to maintain the air quality expected from compliance with ASHRAE's standards.

Air Cleaning

Air cleaning involves the physical or chemical removal of pollutants from the indoor air. Three basic technologies have been developed: particulate filtration, electrostatic precipitation, and gas or vapor sorption.

Air Cleaning Technologies

Particulate Matter Filtration: Filtration removes airborne particles by inertial impingement, interception, straining, and/or diffusion (NRC, 1981). Inertial impingement collects airborne particles on filter material as the direction of air flow changes abruptly. Based on the principle of momentum, this method most effectively removes larger particles. Interception is a special case of impingement in which particles in the air stream collide with and collect on filter material. Interception does not rely on high rates of flow as does inertial impingement. Straining of particulates from the airstream results from the capture of particles between closely spaced filter fibers. Diffusion removes pollutants from the air through the random molecular movement of small particles onto filter material. Each of these mechanisms preferentially removes particles of a different size class. By properly designing air flow and filter materials, a combination of these mechanisms may provide suitable particulate removal (NRC, 1981).

Three kinds of filters corresponding to different levels of efficiency are commonly applied for distinct purposes. Different measures of performance are applied to each type. Low-efficiency filters are used as upstream prefilters (which remove coarse particulate matter from an air stream before it is filtered by more efficient filters) or to protect fans and other air handling equipment. These filters remove large, heavy particles. The weight arrestance test in ASHRAE Standard 52-76 is generally used to evaluate performance of these filters. Medium-efficiency filters are more expensive than their low-efficiency counterparts and remove smaller particles for material and general health protection. The dust spot efficiency test in ASHRAE Standard 52-76 normally used to measure performance of these filters. High-efficiency particulate air (HEPA) filters, more expensive still, can be used for health protection in especially sensitive situations such as clean-room and surgical suite applications. Military Standard 282 which measures the percent removal of 0.3 um particles of dioctylphthalate (DOP) is used to measure performance of these filters.

Electrostatic Precipitation: An alternative method of removing particles from air, electrostatic precipitation, induces a charge on the particles and then collects the charged particles on oppositely charged surfaces. Electrostatic precipitation requires three steps: (1) air ionization, (2) particle charging, and (3) particle migration (Fisk et al., 1985). Air ionization occurs in the vicinity of a high voltage electrode in direct contact with air. The high voltage creates an electric field which ionizes gas molecules. Ionized gas molecules, or the electrons they release, disperse into the air and attach to particles. The charged particles created thereby are drawn toward oppositely charged surfaces at rates dependent on their electrical charge and size.

The efficiency of electrostatic precipitation is measured similarly to that of filters, and its performance compares to medium-efficiency and HEPA filters. This technology presents potential problems in the form of high voltages at the ionizing location, as well as the production of ozone.

Gas Sorption: Gases are removed from air by chemical and physical sorption. Sorption processes include absorption of air pollutants into sorbent material, fixation of pollutants onto external surfaces, and physical or chemical adsorption on internal surfaces (NRC, 1981).

Adsorption is a dynamic process, and its effectiveness in removing pollutants depends on the concentration of the pollutant in the atmosphere, the surface area of the sorbent, the volume of pores small enough to facilitate condensation of adsorbed gases, the presence of competing gases, and the physical and chemical nature of adsorbate and sorbent (NRC, 1981). Common sorbents include neutral substances, such as activated carbon, and more selective, oxygenated substances, such as activated alumina and silica.

Sorbents can be impregnated with substances that enhance the sorption process. Potassium permanganate is an example of a compound that enhances sorbent efficiency by oxidizing air contaminants to facilitate their interaction with the sorbent.

Air Cleaning Devices

Because different technologies perform different types of air cleaning functions, these varied air cleaning technologies may be incorporated into integrated air cleaning systems. Multi-stage devices are needed if air cleaning is to remove both particulate and gaseous air pollutants. These devices can be incorporated into central air systems to treat ventilation air or can stand alone and treat ambient air drawn through a cleaning system independent of ventilation.

The effectiveness of air cleaning devices depend on the air flow rate, as well as removal efficiency. The effectiveness of portable units may also depend on their location in the room. This is particularly true of ion generators which are most effective when centrally located.

HVAC Air Cleaning Systems:

Typical air cleaning components in HVAC systems are comprised of low-efficiency filters that remove only the largest of airborne particles. Filters to remove the smaller viable microbes and respirable particles are not generally used except in special applications such as nuclear industry facilities and sensitive areas of health care facilities. These highly efficient (HEPA) filters are rarely used because they are expensive to install and operate (Fisk, 1986).

Electrostatic precipitation is used in HVAC systems to remove particulate air pollutants. These devices, however, emit ozone which may be a problem if the unit is oversized.

Gas sorpents include activated carbon, silica, and alumina, the choice of which depends on the pollutants of concern. A promising HVAC-related air cleaner currently under development would use desiccant materials in a vapor compression air conditioner to remove gases such as NO_x (Relwani et al., 1987; Novosel et al., 1987).

Stand-Alone Units: Stand-alone air cleaning devices have been developed as indoor air quality concerns have become more prevalent. The performance of these devices, which utilize ion generators and filters, varies considerably.

Consumer Reports (1985) tests of twenty-three portable air-cleaning units found that only eight appliances could effectively clean ETS and pollen-size particles from indoor air. These eight units appear to be capable of removing only particulate matter. An example of a stand-alone device that may provide some gas removal capability is a one square foot filter which was shown to reduce CO concentrations by 34 percent in test studies (Collins, 1986).

Despite the effectiveness of some models, Consumer Reports concluded that "small, inexpensive air cleaners are almost useless" in providing indoor air quality control (Consumer Reports, 1985). Fisk (1986) confirms these results in claiming that tabletop air cleaners are almost totally ineffective in removing pollutants. The ineffectiveness of many portable devices relates not to their ability to remove pollutants from the air they process, but in their limited ability to circulate a significant portion of the indoor atmosphere, and the potential emission of pollutants from their air cleaning surfaces when improperly maintained.

Difficulties in Cleaning ETS

ETS has proven to be a difficult pollutant to control by air cleaning (Bearg and Turner, 1987). This difficulty arises largely because of the complexity of the ETS mixture. Olander and coworkers (1987) attempted to clean ETS from air with over thirty devices and concluded that no air cleaning device could replace dilution control for removal of this pollutant. Peltier (1986), in a theoretical study, determined that ETS cleaning required the processing of seventeen times more air for particulate removal than for gas removal. Repace and Lowery (1985) calculated that it would require about 250 times as much ventilation air as standards require for offices to control the lung cancer risk from the particulate phase of ETS to an "acceptable" level of risk. This leads to the conclusion that ETS is best controlled by smoking bans, or by restricting smoking to rooms that are depressurized relative to the nonsmoking part of the building and directly exhausted to the outside.

Summary of Control Strategies

The control strategies discussed in this chapter span a variety of control mechanisms and vary in their accessibility to parties interested in the control of indoor air quality. Exhibit 6-1 illustrates the agents who can implement these control opportunities and presents brief comments on the range of problems that each category of strategies can address.

Source strategies are limited to the extent to which sources can be identified and are accessible to the responsible agent. Some form of source control is generally available to consumers and building managers. However, source substitution and modification of building materials must, for the most part, be done before buildings are occupied, so occupant and building manager options in this regard are limited. Source maintenance and operation control are entirely in the hands of the user of the source, and cannot be practically influenced by builders, designers, or product manufacturers. Manufacturers can in many cases modify the composition and/or characteristics of their products in ways that would improve indoor air quality.

Ventilation approaches to indoor air quality control can effectively remove all airborne contaminants, but are limited by ventilation system design and the presence of sources that emit pollutants too rapidly to be well dispersed by dilution. Because ventilation capacities are determined in the building design stage, most existing systems may not be flexible enough to allow

Exhibit 6-1
Control Strategy Summary

CONTROL STRATEGY	AGENTS WHO CAN IMPLEMENT CONTROL STRATEGY			COMMENTS
	Consumers, Occupants, & Building Managers	Builders & Designers	Building & Consumer Product Manufacturers	
Source Control				Controls indoor concentrations of pollutants which have attributable sources.
Substitution/Removal	X	X		Performed during construction or renovation. Voluntary or required in building code. Smoke-free buildings designated by occupants, building managers, or by regulation.
Encapsulation/Confinement	X	X		Performed during design, construction, or renovation. Voluntary or required in building code. Smoke-free areas designated by building managers or regulators.
Operation and Maintenance	X			Performed during building occupancy by parties operating the building. Voluntary or regulated in health or fire codes for some building types.
Modification	X		X	Performed by occupants, building managers, builders, or manufacturers. Voluntary or regulated in building codes or product standards.
Ventilation Control				Controls indoor concentrations of ALL airborne contaminants.
General	X	X		Operated by occupants or building manager. System design influences performance. Minimum rates may be mandated in building codes.
Local	X	X		Operated as required by occupants or building manager. Performance influenced by design. Building codes may require local exhaust from certain sources and activities.
Pollution-Induced	X	X		Experimental.
Air Cleaning				Controls indoor concentrations of particulates and reactive gases.
Stand Alone	X			Installed and operated by building occupants or managers. Maintenance by occupants or managers necessary for proper operation. Unit capacity must be matched to room volume. Many units are ineffective.
HVAC-Based	X	X		Operated by building managers. Installed during building construction or as a renovation.

their use to control all air quality concerns. Ventilation design and operation for indoor air quality control are frequently sacrificed for energy efficiency; air quality control can be greatly impaired if indoor air concerns are subjugated to concerns for energy consumption. Because of limitations inventilation capacity or practice, building occupants and managers often cannot take full advantage of pollution control by ventilation.

Air cleaning may be added to ventilation control of particulate and reactive gas pollution problems when incorporating sufficient outside air is not feasible. When the outside air requires extensive conditioning for thermal comfort, ventilation can be a costly control method, and some recirculation with added cleaning of indoor air becomes economically attractive. HVAC-based air cleaners are preferred. Many available stand-alone air-cleaning units provide almost no assistance in removing contaminants. All air cleaners must be properly operated and maintained to be effective.

6.2 APPROPRIATE DESIGN AND MAINTENANCE FOR BUILDINGS

Because of the important role building systems play in determining indoor air quality, building design and maintenance provide excellent opportunities to control potential indoor air problems. Appropriate design of interior space, mechanical systems, and the building envelope can optimize the air quality potential of a building, and proper maintenance can ensure that building operation maximizes indoor air quality to the extent allowed by design.

Design Requirements for Indoor Air Quality Control

Appropriate building design for indoor air quality encompasses such considerations as HVAC system design, building envelope and structure design, and spatial layout of interior activity areas and their relationship to potential indoor and outdoor pollutant sources. Design of these components to optimize indoor air quality must work within the constraints of other building system performance requirements such as structural integrity, economic viability, and comfort and safety issues related to lighting, noise, and temperature.

HVAC engineers and architects typically provide the professional support needed to assure that the full array of performance requirements are met by a building's design. The traditional separation of design roles between HVAC engineers and architects may prohibit either discipline from adequately addressing all design requirements independent of the other. The following discussions of important building design components point to the necessary cooperation between these professions in properly designing building systems.

HVAC Design Criteria

HVAC design criteria serve to ensure that the indoor atmosphere can be conditioned to provide thermally comfortable air throughout the occupied zone of a building. In addition to thermal comfort, indoor air quality design goals should also be incorporated. They may be prescribed in building codes or standards. Design goals are achieved by (1) supplying adequate outdoor ventilation air, (2) properly distributing the outdoor air throughout the occupied zone, and (3) taking further steps as necessary to ensure that the resulting air of the occupied zone does not contain deleterious concentrations of airborne contaminants.

HVAC system design must balance ventilation with indoor source emissions and outdoor pollutant levels to create an acceptable indoor atmosphere. Consideration of indoor sources requires consulting with the building's architects and owner to learn of planned uses of the space and materials employed in constructing, decorating, and furnishing the building. The potential introduction of contaminants from sources outdoors, including those on the exterior of the building (e.g. exhaust vents), necessitates attention to the location and design of air intakes to prevent contaminated air from entering the building, restricting entry of contaminants by creating positive interior pressures, and, if necessary, pre-treating ventilation air.

Building Envelope and Structure Design Requirements

Appropriate design of building systems recognizes the importance of the building structure to the indoor atmosphere. Materials must meet criteria for durability, structural integrity, functional utility, and ease of maintenance. They should also meet low pollutant emission criteria. Characterizing potential pollution sources in a building structure during the design stage can allow their effects to be mitigated through substitution or other appropriate source or ventilation controls before they create indoor air problems.

Building envelopes may be designed to minimize infiltration and exfiltration for energy conservation reasons. Adequate outdoor air ventilation must be designed into the building structure, and can be provided by natural or mechanical means. Buildings designed to minimize infiltration and exfiltration must provide adequate outdoor air ventilation through mechanical means. Roof designs must minimize water accumulation and leakage to minimize biological contamination and structural damage.

Sub-slab ventilation can be designed into new building construction to indoor radon problems. Several of the nation's largest home-building firms are currently "roughing-in" provisions for sub-slab ventilation in all new residential construction (Spears, 1988).

Interior Space Design Requirements

Interior space design must provide adequate floor space for occupant activities, and meet aesthetic, acoustic, light, and privacy requirements. It should also maintain occupant exposures to indoor pollutants below detrimental levels. Future occupant exposures to indoor air pollutants can be controlled through source confinements, locating problem sources away from occupied areas, and using air flow patterns to draw source emissions away from occupants. Care must be taken in the selection and location of movable partitions which can be pollutant sources and may also interrupt the flow of ventilation air to building occupants.

Maintenance Requirements for Indoor Air Quality Control

Proper maintenance allows building performance to meet or exceed design goals for indoor air quality. The performance requirement of indoor air quality protecting the health, comfort, and productivity of occupants can be advanced through proper maintenance of occupied spaces and the HVAC system (Levin, 1987b). Cleaning and maintenance can themselves create indoor air pollution by suspending accumulated pollutants and should therefore be conducted so as to minimize exposures to elevated contaminant concentrations (Green, 1984).

Occupied areas need to be maintained as free as practical accumulations of dust, microorganisms, and pests. General hygiene usually suffices to control dust accumulation and microorganism growth, as well as pest populations.

The humidity of the building system affects microorganism viability, and should be limited to prevent fungal and bacterial amplification and subsequent accumulation. Water damaged materials should be discarded if feasible to prevent microbial contamination. Contaminated building surfaces should be vacuumed using a vacuum cleaner incorporating a HEPA filter and subsequently disinfected (Rask and Morey, 1987). Microbial damage is difficult and costly to clean and should be scrupulously avoided. Cleaning may not be possible where severe contamination occurs.

Maintenance of HVAC systems includes keeping them clean of dust, microorganisms, and water accumulations; maintaining mechanical parts; and operating under conditions to achieve design requirements for air flow and distribution, temperature, and humidity (Rask and Morey, 1987).

6.3 DIAGNOSTIC PROTOCOLS FOR INDOOR AIR QUALITY CONTROL

Building diagnostic protocols provide standardized methods to assess the current and future performance of building systems. Indoor air quality diagnostics focus on assessments of those components of building system performance which affect indoor air quality. Through diagnostic protocols, expert observers and analysts can identify indoor air problems and recommend remedial actions to address building design and operation difficulties.

Building diagnostics provide expert assessment of the degree to which individual building performance requirements are met, the degree to which the overall building purpose is being served, implications of deficiencies in building performance, and causes of performance deficiencies which suggest remedial actions. The relevant individual building performance requirement in indoor air quality diagnostics is the ability of the indoor atmosphere to sustain the health, comfort, and productivity of building occupants.

Building diagnostic protocols call for a series of steps to fully characterize building performance and to relate that performance to goals and design expectations. Woods et al. (1987) describe phases in the diagnosis of buildings experiencing indoor air quality problems as (1) consultation, (2) qualitative diagnostics, and (3) quantitative diagnostics. These phases are defined and explained in Exhibit 6-2 by the procedures they entail and the information that they are designed to provide. By performing diagnoses in this staged manner, it is possible to prevent and resolve many problems without resorting to time and resource-consuming data acquisition unless absolutely necessary (Woods et al., 1987).

Specific actions performed as diagnostic aids include measuring physical criteria, and interviewing building managers, facilities staff, and occupants. Physical criteria which might point to air quality problems include indoor temperature, humidity, and pollutant concentrations; characterization of possible pollutant sources in the building system; operating conditions of HVAC systems; and outdoor conditions which might influence the indoor environment. Occupant interviews can provide information on perceived detrimental effects potentially associated with poor building performance, and the temporal and spatial extent and patterns of such effects. These data can then be analyzed as part of the assessment of building performance.

Since indoor air quality problems can result from such a variety of factors, manifest themselves in such diverse ways, and can hinder the proper functioning of building systems, building diagnostic procedures (and explicit, structured protocols to conduct them) are essential to the control of indoor air quality. Performing diagnostic evaluations on a regular basis can prevent

Exhibit 6-2
Indoor Air Quality Diagnostic Protocol [a]

STAGE	PROCEDURE	PURPOSE
Consultation	Meet with Senior Administrative Officer and Safety Officer	Explain objectives and acquire preliminary information.
	Meet with Facilities Manager/Staff	Acquire information about building system characteristics.
	Tour Facility	Inspect occupied spaces and mechanical equipment to determine condition of space, to observe HVAC performance, and to communicate with occupants.
	Develop Hypotheses and Recommendations	Focus attention on possible recommendations for remedial action or additional phases of diagnosis.
Qualitative Diagnostics	Establish Performance Criteria in Consultation with Building Owner's Representative	Determine limits of acceptable indoor air quality.
	Characterize Occupant Problems or Complaints through Interviews	Learn extent of problem and its relation to building layout and performance.
	Define System Boundaries	Limit scope of further study to problem area.
	Analyze Control Strategies	Assess differences between design and actual building system performance.
	Analyze Loads	Assess HVAC system capabilities to cope with environmental requirements. This may include simulations or tracer gas tests of HVAC components.
	Report	Communicate findings and additional recommendations to the client.
Quantitative Diagnostics	Select Sampling Sites	Prepare for cost-effective, thorough collection of air samples.
	Objective Measurement	Coordinate measurements of occupied space and HVAC system to correlate indoor conditions to HVAC performance. Quality assurance and quality control of these data guarantee their utility.
	Subjective Measurement	Assess occupant response to environmental conditions at the time that objective measurements are taken.
	Analysis, Interpretation, and Report	Assess and communicate information gained during the diagnoses. Report should identify causal agents of and practical remedies for observed problems.

[a] Summary of protocol described by Woods et al. 1987.

air quality problems from occurring or minimize their duration and magnitude.

6.4 ADMINISTRATIVE CONTROL OPTIONS

The previous sections of this chapter covered the physical control methods that could be used to prevent and mitigate indoor air pollution in both new construction and in existing buildings. The agents capable of employing these methods include individual occupants, building owners and managers, architects, builders, and manufacturers.

Public and private sector organizations, including trade and professional associations, consumer and health organizations, and governments, also have significant roles to play in terms of informing, encouraging, or requiring these agents to take action to protect building occupants. Exhibit 6-3 provides examples of individual and organizational roles.

In this section, we discuss regulatory and non-regulatory policy options available to organizations and governments in fulfilling these roles. Subsequent chapters will discuss the actual policies and programs which are currently in place.

Government Regulations

Regulations impose requirements on individuals or organizations in the conduct of activities which pose a threat to the public health and welfare, and are commonly regarded as the main policy instrument for environmental protection. Because environmental regulations carry the force of law, and generally contain provisions for either civil or criminal penalties for non-compliance, their use is normally limited only to situations of significant risk, and follow directly from legislation specifically authorizing such regulations.

Legislative authorities specifically authorizing regulations which affect indoor air, and examples of government regulations employed under those authorities are discussed in subsequent chapters. The most common types of regulations are those which are specific to a given pollutant or source. Such regulations may take several forms:

- a ban or restriction on the use of specific chemicals or products;
- requirements that products meet certain standards;
- requirements that products be tested and certified prior to manufacture; or

Exhibit 6-3
Public and Private Sector Roles

INDIVIDUALS	CONSUMER AND HEALTH PROFESSIONALS	MANUFACTURERS	BUILDING OWNERS AND MANAGERS	BUILDERS AND ARCHITECTS	STATE AND LOCAL GOVERNMENTS	FEDERAL GOVERNMENT
1. Find low emission products in purchasing decisions.	1. Be knowledgeable of symptoms, effects and mitigation and advise clients.	1. Adopt test procedures and standards to minimize product and material emissions.	1. Adopt ventilation maintenance procedures to eliminate and prevent contamination and ensure an adequate supply of clean air to building occupants.	1. Adopt indoor air quality as a design objective.	1. Conduct studies of specific problems in state or local area and adopt mitigation strategies.	1. Conduct research and technology transfer programs.
2. Maintain and use products to minimize emissions.	2. Develop information and education programs to constituent publics.	2. Adequately label products as to emission level and proper use and maintenance of products.	2. Use zone ventilation or local exhaust for indoor sources.	2. Ensure compliance with indoor air quality ventilation standards.	2. Establish building codes for design, construction, and ventilation requirements to ensure adequate indoor air quality.	2. Coordinate actions of other sectors.
3. Exercise discretionary control over ventilation to ensure clean air supply.		3. Substitute materials to minimize emissions from products manufactured.	3. Develop specific procedures for use of cleaning solvents, paints, herbicides, insecticides, and other contaminants to protect occupants.	3. Adopt low emission requirements in procurement specifications for building materials from manufacturers.	3. Enforce and monitor code compliance.	3. Conduct specific programs to inform, encourage, or require specific sectors to take actions toward mitigation.
4. Be knowledgeable of indoor air quality problems and take actions to avoid personal exposure.		4. Develop training programs for commercial users to ensure low emissions.	4. Adopt investigatory protocols to respond to occupant complaints.	4. Contain or ventilate known sources.	4. Educate and inform building community, health community, and public about problems and solutions.	
		5. Conduct research to advance mitigation technology.				

- requirements that products be labelled with important information concerning content, effects, and proper instructions for use.

Some regulatory requirements may be in the form of standards or guidelines which are discussed below.

Standards and Guidelines

Standards and guidelines are frequently issued by private sector organizations as well as governments. The standards and guidelines may be mandatory (regulatory) or voluntary (non-regulatory), but the distinction is not always clear. For example, while the majority of private sector standards are voluntary, they may be as effective as a government regulation because they become the basis for professional practice and, as such, are often used for licensure. Compliance with such standards may also be necessary for protection against liability. Thus, a violation of a private sector standard may carry with it sanctions which are similar to or more stringent than government regulations.

In addition, standards set or adopted by organizations such as the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), the American Conference of Governmental Industrial Hygienists (ACGIH), and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) are often incorporated into government regulations either directly or by reference, and in that way become mandatory.

Standards or guidelines most relevant to indoor air include air quality standards; source emission standards; ventilation standards; building codes; and diagnostic protocols.

> Air quality standards specify maximum concentration levels of a contaminant beyond which health risks from exposure are deemed to be unacceptable. Standards will vary according to the level of protection, the population protected, and the extent to which technical and economic feasibility are taken into account. A discussion of available indoor air quality standards is given in Chapter 7.

> Source emission standards specify maximum rates at which a contaminant can be emitted from a source. The rates are designed to protect the user and/or third parties that might be exposed. Such standards are normally imposed on the manufacturer.

Ventilation standards specify minimum rates for the introduction of outdoor air into indoor spaces. Standards are designed to service occupant needs for temperature, humidity, and air quality control. Rates will vary with occupant density and activity. Available ventilation standards are discussed in Chapter 7.

Building codes provide design and construction specifications for buildings. Portions of building codes which are important to indoor air quality include ventilation specifications which affect the dilution and exhaust capacity of the ventilation system, material specifications which affect emission rates of building materials, and design specifications which affect the overall relationship between sources, pollutant transport, and human activity. Most building codes are administered by State and local governments.

Diagnostic protocols establish methodologies for measuring and assessing indoor air quality problems. A comprehensive system of protocols for indoor air would include criteria and measurement methods for assessing occupant health, building system performance, and building air quality. No such comprehensive set of protocols for indoor air has yet been developed, though specific elements are being addressed by a number of individuals and organizations.

Non-regulatory Options

Non-regulatory policy instruments include research, coordination, training and technical assistance, and public information. These activities are both complements, and in some cases, alternatives to regulations.

Research on indoor air pollution is essential to determine the nature and magnitude of the problem including its causes, consequences, and methods of control. Information from research activities forms the foundation for policy development and control in both the public and private sectors. Research is normally coupled with technology transfer activities to ensure that information from research is "transferred" to potential users in order to facilitate the implementation of control programs.

Coordination is a policy function designed to ensure efficient implementation of policy objectives among several players. Coordination may be used to eliminate duplication, to share information, or to integrate actions into a common program guided by common objectives. True integration is seldom achieved among federal agencies because of the disparity between agency legislative mandates. The interagency Committee on Indoor Air Quality (CIAQ) is a formal arrangement for coordinating federal activities in indoor air.

Training and technical assistance programs are policy instruments by which individuals receive technical information or develop expertise for implementing policy objectives. Training and technical assistance programs for indoor air may be used to build capacity among state and local governments or the private sector for solving problems, or for establishing indoor air quality programs.

Public information dissemination is particularly relevant to indoor air because of the sometimes wide degree of control that individuals have in limiting their own exposure to indoor pollutants. Individuals' behaviors which affect exposure and health include choices in the products they purchase, the storage and use of those products, and actions they take to properly ventilate occupied spaces. Examples of public information activities include fact sheets, booklets, handbooks, press releases, and workshops.

Choices Among Administrative Options

Administrative options may be as mild as public education, or as stringent as an absolute ban on the use of certain chemicals. Programs may be centrally focused in the federal government, may be decentralized and delegated to state and local governments, or may be primarily left to the private sector with coordinated governmental involvement.

Choices will depend on a full understanding of the multiplicity of issues and control options. Problems can occur in large commercial office buildings, in private homes, and in restaurants and other public spaces. Sources include building materials (e.g. treated wood products), combustion products (e.g. kerosene heaters), office equipment (e.g. copying machines), and consumer products (e.g. pesticides). Causes may be natural (e.g. radon gas) or human behavior (e.g. smoking).

Mitigation alternatives are likewise numerous and complex, ranging from modifying or substituting sources, to treating the air or changing behaviors. Moreover, the agents which can effect change include a wide variety of individual, professional, institutional, and governmental actors.

A comprehensive program will include a mix of administrative options. Each may be targeted to a different need. In making choices, several issues will have to be considered:

- the extent of health risks, and whether they are voluntary or involuntary;

- the energy and economic impacts involved;
- whether a particular issue involves acute health effects requiring immediate response, or chronic health problems requiring long-term strategies;
- whether the problem being addressed is best characterized in terms of a few high-risk pollutants and sources, or as a multifactorial problem involving mixtures of diverse pollutants, sources, building system parameters, and varied human sensitivities; and
- whether protection should be directed at the general public, or specific sub-populations including the elderly, the young, and the hypersensitive, who may have special needs.

6.5 SUMMARY

Engineering options available to control indoor air quality include source control, ventilation, and air cleaning strategies. Source control is preferred where sources are known and control at the source is feasible. Ventilation is a necessary component to any control strategy but ventilation alone does not guarantee good indoor air quality. Air cleaning is a useful adjunct to other control strategies, and is more generally available for controlling particles than for controlling gases and vapors.

Good building design, maintenance and operational practices which incorporate indoor air quality control principles are mechanisms by which indoor air quality may be achieved and maintained in buildings. Diagnostic protocols are needed to insure that where problems occur, they can be adequately diagnosed and mitigated. Finally, administrative controls may be regulatory or non-regulatory. Administrative controls may be used by governments and others to encourage or require that the engineering controls, the design, maintenance and operational practices, and the diagnostic protocols described above are appropriately followed.

REFERENCES

ASHRAE. 1986. ASHRAE Proposed American National Standard: Ventilation for Acceptable Indoor Air Quality. Public Review Draft. ASHRAE 62-1981R. Atlanta GA.

ASHRAE. 1981. ASHRAE Standard: Ventilation for Acceptable Indoor Air Quality. ASHRAE 62-1981. Atlanta GA.

Bearg D.W., Turner W.A. 1987. Achieving Tobacco Smoke-Free Environments: The Problem and Some Solutions. pp. 334-337. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Boelter F.W., Monaco E.A. 1987. Ventilation Modification in a Parking Structure. pp. 41-46. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Collins, M. 1986. Room Temperature Catalyst for Improved Indoor Air Quality. pp. 448-460. Transactions of an APCA Specialty Conference. Indoor Air Quality Control in Cold Climates: Hazards and Abatement Measures. Walkinshaw D.S. (Ed.).

Consumer Reports. 1985. Air Cleaners. January 1985. pp. 7-11. Consumers Union.

D'Angelo W.C., Spicer R.C., Mease M.J. 1987. Sophisticated Asbestos Removal: Occupied Buildings and Operating HVAC Systems. pp. 119-130. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Dement J.M., Smith N.D., Hickey J.L.S., Williams T.M. 1984. An Evaluation of Formaldehyde Sources, Exposures, and Possible Remedial Actions in Two Office Environments. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 3:99-104.

DeWerth D., Kurzynske R. 1986. Burner Flame Inserts for Lower NO_x Emissions. pp. 437-447. Transactions of an APCA Specialty Conference. Indoor Air Quality Control in Cold Climates: Hazards and Abatement Measures. Walkinshaw D.S. (Ed.).

Environmental Protection Agency. 1987. Radon Reduction Methods. A Homeowner's Guide. Second Edition. Office of Research and Development. OPA-87-010. Washington, D.C.

Ericson S.O., Schmeid H., Clavensjo B. 1984. Modified Technology in New Construction, and Cost Effective Remedial Actions in Existing Structures, to Prevent Infiltration of Soil Gas Carrying Radon. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 5:153-158.

Fecker I., Hangartner M., Wanner H.U. 1987. Measurement of Carbon Dioxide of Indoor Air to Control the Fresh Air Supply. Indoor Air '87: Proceedings of the Fourth International Conference on Indoor Air Quality and Climate. Seifert B., Esdorn H., Fischer M., Ruden H., Wegner J. (Eds). Berlin (West). 2:635-639.

Fisk W.J., Spencer R.K., Grimsrud D.T., Offerman F.J., Pederson B., Sextro R. 1985. Indoor Air Quality Control Technologies. A Critical Review. Bonneville Power Administration. Conservation Engineering Branch. Division of Resource Engineering.

Fisk W.J. 1986. Research Review: Indoor Air Quality Control Technologies. pp. 568-583. Proceedings of the ASHRAE Conference IAQ 86: Managing Indoor Air for Health and Energy Conservation. Atlanta GA.

Frey A.H. 1987. Control of a Severe Odor Problem in a Building. pp. 265-274. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Giles J.H. 1987. The Benefits of Using Filtered and Recirculated Air as Ventilation Air. pp. 275-280. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Godish T., Rouch J. 1987. Control of Residential Formaldehyde Levels by Source Treatment. Indoor Air '87: Proceedings of the Fourth International Conference on Indoor Air Quality and Climate. Seifert B., Esdorn H., Fischer M., Ruden H., Wegner J. (Eds). Berlin (West). 3:221-225.

Godish T., Rouch J. 1984. Efficacy of Residential Formaldehyde Control Measures: Source Removal. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 3:127-132.

Green G.H. 1984. The Effect of Vacuum Cleaners on House Dust Concentration. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 5:87-92.

Guttman K. 1987. Proposed Method of Indoor Air Pollution Control by Dilution with Outside Air. pp. 223-232. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Henschel P.B., Scott A.G. 1987. Some Results from the Demonstration of Indoor Radon Reduction Measures in Block Basement Houses. Indoor Air '87: Proceedings of the Fourth International Conference on Indoor Air Quality and Climate. Seifert B., Esdorn H., Fischer M., Ruden H., Wegner J. (Eds). Berlin (West). 2:340-346.

Kalnins R., Guadert P.C. 1986. Formaldehyde Emissions from Typical Particleboard Applications and Assessment of Specific Abatement Measures. pp. 402-412. Transactions of an APCA Specialty Conference. Indoor Air Quality Control in Cold Climates: Hazards and Abatement Measures. Walkinshaw D.S. (Ed.).

Levin H. 1987a. The Evaluation of Building Materials and Furnishings for a New Office Building. pp. 88-103. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Levin H. 1987b. Protocols to Improve Indoor Environmental Quality in New Construction. pp. 157-169. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Levin H., Hahn J. 1984. Pentachlorophenol in Indoor Air: The Effectiveness of Sealing Exposed Pressure-Treated Wood Beams and Improving Ventilation in Office Buildings to Address Public Health Concerns and Reduce Occupant Complaints. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 5:123-130.

Matthews T.G., Dreibelbis W.G., Thompson C.V., Hawthorne A.R. 1986. Preliminary Evaluation of Formaldehyde Mitigation Studies in Unoccupied Research Homes. pp. 389-401. Transactions of an APCA Specialty Conference. Indoor Air Quality Control in Cold Climates: Hazards and Abatement Measures. Walkinshaw D.S. (Ed.).

Meyer B. 1983. Indoor Air Quality. Addison-Wesley. Reading MA.

Moschandreas D.J. 1987. Indoor Air Pollution Controls. Indoor Air '87: Proceedings of the Fourth International Conference on Indoor Air Quality and Climate. Seifert B., Esdorn H., Fischer M., Ruden H., Wegner J. (Eds). Berlin (West). 4:91-103.

Mudarri, D.H. 1986. Toward a National Strategy for the Mitigation of Indoor Air Pollution. Paper presented at the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, MN.

NRC. 1987. Building Diagnostics: A Conceptual Framework. National Academy Press. Washington, D.C.

NRC. 1981. Indoor Pollutants. National Academy Press. Washington, D.C.

Novosel D., Relwani S.M., Moschandreas D.J. 1987. Development of a Desiccant-Based Environmental Control Unit. pp. 261-263. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Olander L., Johansson J., Johansson R. 1987. Air Cleaners for Tobacco Smoke. Indoor Air '87: Proceedings of the Fourth International Conference on Indoor Air Quality and Climate. Seifert B., Esdorn H., Fischer M., Ruden H., Wegner J. (Eds). Berlin (West). 2:39-43

Peltier R.G. 1986. Tobacco Smoke Ventilation and Air Cleaners: Particulates versus Gases. pp. 611-617. Proceedings of the ASHRAE Conference IAQ 86: Managing Indoor Air for Health and Energy Conservation. Atlanta GA.

Rask D.R., Morey P.R. 1987. Strategies for Indoor Air Control of Bioaerosols in Office Buildings. Presented as the 80th Annual Meeting of APCA. New York. June 21-26, 1987.

Relwani S.M., Moschandreas D.J., Billick I.H. 1987. Indoor Air Quality Control Capabilities of Desiccant Materials. Indoor Air '87: Proceedings of the Fourth International Conference on Indoor Air Quality and Climate. Seifert B., Esdorn H., Fischer M., Ruden H., Wegner J. (Eds). Berlin (West). 3:236-240.

Repace & Lowrey. 1985. An Indoor Air Quality Standard for Abient Tobacco Smoke based on Carcinogenic Risk. New York State Journal of Medicine, Vol. 85.

Revzan K.L. 1984. Effectiveness of Local Ventilation in Removing Simulated Pollution from Point Sources. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 5:65-71.

Spears J. 1988. National Research Center, National Association of Home Builders. Personal Communication.

Sterling T.D., McIntyre E.D., Sterling E.M. 1987a. Reducing Radon Levels in Tightly Sealed Residences Through Crawlspace Mechanical Ventilation. pp. 132-136. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Sterling E.M., Collett C.W., Mueller B., Meredith J., Blomfield T. 1987b. Case Studies of Ventilation Retrofits Designed to Resolve Air Quality Problems in Public Buildings. pp. 308-317. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Ueno Y. 1984. The Effects of Ventilator, Air Cleaner, and Humidifier on Indoor Air Pollution Caused by Cigarette Smoking in a House. Indoor Air, Proceedings of the Third International Conference on Indoor Air Quality and Climate. Berglund B., Lindvall T., Sundell J. (Eds.). Stockholm. 5:131-135.

Vaculik F. 1987. Air Quality Control in Office Buildings by a CO_2 Method. pp. 244-251. Proceedings of the ASHRAE Conference IAQ 87: Practical Control of Indoor Air Problems. Arlington VA.

Woods, J.E., Morey, P.R., and Rask, D.R., 1987. Indoor Air Quality Diagnostics: Qualitative and Quantitative Procedures to Improve Environmental Conditions. Presented at the Symposium on Design and Protocols for Monitoring Indoor Air Quality, sponsored by ASTM, Cincinnati, Ohio.

CHAPTER 7 - EXISTING INDOOR AIR QUALITY STANDARDS AND GUIDELINES

The purpose of this chapter is to characterize the public health standards most commonly used to address indoor air quality problems. Standards covered include:

- National Ambient Air Quality Standards established by the U.S. Environmental Protection Agency (EPA),
- Air Quality Guidelines for Europe established by the United Nations' World Health Organization (WHO),
- Ventilation Standards for Acceptable Indoor Air Quality established by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), and
- Exposure Guidelines for Residential Indoor Air Quality established by the Canadian Ministry of National Health and Welfare.

The chapter briefly describes how each organization establishes its standards or guidelines, noting in particular the primary public health objectives each standard or guideline addresses.

For comparative purposes, the chapter also reviews several occupational standards and guidelines. Occasionally, occupational standards are used to address indoor air quality problems in non-industrial environments when appropriate public health standards are unavailable. The occupational standards covered include: Permissible Exposure Limits established by the U.S. Occupational Safety and Health Administration (OSHA), Recommended Exposure Limits established by the U.S. Department of Health and Human Services' National Institute for Occupational Safety and Health (NIOSH), and Threshold Limit Values established by the American Conference of Governmental Industrial Hygienists (ACGIH).

The remainder of this chapter is organized as follows:

- Characterization of Standards: a brief discussion of the primary public health objectives the standards and guidelines address.
- Compilation of Standards: matrix of observed indoor air pollutants and existing exposure standards and guidelines for each substance.

- Evaluation: discussion of broad differences among public health and occupational standards, and identification of important gaps among existing health standards that pertain to indoor air quality.

- Ventilation Standards: discussion of ventilation requirements for the control of indoor air quality.

- Summary: existing public health standards and guidelines and their applicability to indoor air quality problems.

7.1 CHARACTERIZATION OF STANDARDS

Air quality standards control by law the amount of specific pollutants that are permissible in the air. There are, however, many substances for which there are no standards. In these cases, guidelines can provide useful rules-of-thumb for deciding whether a given situation may be a problem. At times, guidelines are also used as substitutes for standards known to be out of date. Practically all current standards and guidelines focus on exposure to one pollutant at a time.

This section reviews public health standards and guidelines used to address indoor air quality problems. For comparative purposes, several occupational standards and guidelines are also discussed. The discussion is intended to provide a general overview of the concepts, terminology, and guiding principles used to establish each of the standards and guidelines.

Standards and Guidelines for Protecting the General Public

EPA National Ambient Air Quality Standards

EPA establishes National Ambient Air Quality Standards (NAAQS) under authority of the Clean Air Act. Enforcement is limited to outdoor ambient levels. Primary standards are designed to protect the public health, and secondary standards to protect the public welfare (crops, structures, animals, and human comfort). Section 109(b) of the Act prescribes that primary standards allow an adequate margin of safety to protect the public health. Levels are set to protect even sensitive portions of the population (e.g., asthmatics). To establish which standard provides an adequate margin of safety, the EPA considers the extent to which uncertainty exists in the scientific data; however, there is no established system that dictates the manner in which this uncertainty is considered, and this can vary from pollutant to pollutant. The standards protect against short-term (e.g., one hour) and long-term health effects. Technological and cost considerations are not a factor in establishing the standards, but do play a role in implementing the controls necessary to achieve the standards.

The standards specify concentrations of pollutants that cannot be exceeded (or exceeded more than once, or have a probability of being exceeded more than once, depending on the pollutant). They have been promulgated for carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, suspended particulates smaller than 10 microns in diameter (PM-10), and lead. When determining exposure limits and setting its standard, the Agency considers to some extent the possibility of alternate exposure pathways, and the activity level of the exposed populace (see for example the final EPA regulations for lead (43 FR 46246, Oct. 5, 1978) and for carbon monoxide (50 FR 37484, Sept. 13, 1985)).

The states are responsible for enforcing the standards and must develop State Implementation Plans (SIPs) to provide for attainment and maintenance of primary NAAQS by specific dates, and secondary NAAQS within a reasonable time.

[Note: under the Clean Air Act, Section 112, the EPA also establishes National Emission Standards for Hazardous Air Pollutants (NESHAPS). NESHAPS are emission standards set to provide an ample margin of safety from exposure to hazardous pollutants. However, since these are emissions limits rather than limits on air concentrations, they are not included in this report.]

WHO Air Quality Guidelines for Europe

The Regional Office for Europe of the World Health Organization (WHO), an agency of the United Nations, recently published air quality guidelines for 28 organic and inorganic substances. The guidelines were created to help governments make risk management decisions controlling exposure to indoor and outdoor air pollutants. Health effects were the major consideration in establishing the guidelines, though ecological guideline values are recommended for some substances. The guidelines are established to help protect the public health; occupational exposure limits are not addressed. The guidelines either (1) indicate levels combined with exposure times at which no adverse noncarcinogenic effect is expected, or (2) provide an estimate of lifetime cancer risk arising from exposure to substances that are proven human carcinogens or substances for which there is at least limited evidence of human carcinogenicity. Guidelines are set to protect all people in the European region, including sensitive population subgroups such as asthmatics. Both short- and long-term exposures are addressed (WHO, 1987).

ASHRAE Standard 62-1981: Ventilation for Acceptable Indoor Air Quality

ASHRAE Standard 62-1981 defines acceptable indoor air quality as "air in which there are no known contaminants at harmful concentrations and with which a substantial majority (usually 80 percent) of the people exposed do not express dissatisfaction." The objective of the standard is to establish ventilation rates which, under most circumstances, would achieve acceptable indoor air quality while maintaining efficient energy utilization. To do this, the standard contains a ventilation rate procedure and an indoor air quality procedure. The latter procedure references the EPA NAAQS standards and other standards selected from current practices in various states, provinces, and other countries. These standards are designed to cover contaminants from both outdoor and indoor sources. The ASHRAE standards cover 35 substances. For contaminants not contained in the standard, ASHRAE recommends that levels should not exceed 1/10 the occupational standards used in industry. In the case of odors, and some mucous membrane irritants, ASHRAE specifies that the air can be considered to be free of annoying contaminants if at least 20 untrained observers, after exposure for no more than 15 seconds, deem the air to be not objectionable under representative conditions of use and occupancy (ASHRAE, 1981).

Canadian Exposure Guidelines for Residential Indoor Air Quality (Excluding Radon)

In 1981, the Federal-Provincial Working Group on Indoor Air Quality was formed to develop guidelines for concentrations of selected contaminants in residential indoor air. The guidelines were published in 1987 under the authority of the Minister of National Health and Welfare. The guidelines contain specific quantitative limits for nine pollutants or pollutant categories, plus recommendations to eliminate or control exposure for other pollutants for which specification of exposure limits was not practical. Their application is designed for residential environments, and is based on assumptions of 24-hour (i.e., continuous) exposure. The guidelines take into account such factors as "sensitivity of groups at special risk and sources and mechanisms of action of contaminants." The principle guiding the development of the standards was to ensure that there is "negligible" risk to the health and safety of occupants. The working group acknowledges that the levels "may not provide complete protection to the hypersensitive portion of the population which requires extraordinary measures to achieve such protection." Effects from both short-term and long-term (i.e., lifetime) exposures are covered (Environmental Health Directorate, 1986).

Occupational Standards and Guidelines

OSHA Standards

The Occupational Safety and Health Administration (OSHA), which is part of the U.S. Department of Labor, is responsible for protecting workers from unsafe or unhealthful working environments. Pursuant to the Occupational Health and Safety Act of 1970, OSHA sets standards called Permissible Exposure Limits (PELs). In January 1989, the Agency successfully updated the PELs for about 600 hazardous substances found in the workplace during January 1989. The standards are based on the criteria of ensuring that "no worker will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life."

PELs are concentration limits usually set for 8-hour exposures. If a chemical can produce a toxic effect after only a few minutes of exposure, a 5- to 15-minute limit and/or a ceiling will also be set. The ceiling limits must never be exceeded. The 8-hour limit is a time-weighted average (TWA) that may be exceeded as long as the average concentration over the whole period does not exceed the PEL. The PELs are set at levels that will protect the average American worker to the extent feasible. This reflects an explicit acceptance that some sensitive workers may experience adverse health effects at or below the PEL, and an implicit acceptance of the principle of using economic or technological feasibility as a criterion for setting standards.

NIOSH Recommended Exposure Limits

NIOSH is a part of the U.S. Department of Health and Human Services' Centers for Disease Control. Acting under the authority of the Occupational Safety and Health Act, and the Mine Safety and Health Act, NIOSH develops and periodically revises Recommended Exposure Limits (RELs) to potentially hazardous substances or conditions in the workplace. These RELs are submitted to the Department of Labor for their consideration in developing PELs. The submissions to the Department of Labor include sampling and analysis guidelines, suggestions for medical surveillance and record-keeping, work practices, and processes for informing employees of hazards in addition to the concentration levels (RELs).

In formulating these recommendations, NIOSH evaluates all known and available scientific information relevant to the potential hazard (NIOSH, 1988). NIOSH recommendations are published in a variety of documents. Criteria documents specify NIOSH RELs and appropriate preventive measures designed to reduce or eliminate the adverse health effects.

The American Conference of Governmental Industrial Hygienists (ACGIH)

The ACGIH is an association of professional personnel in governmental agencies or educational institutions engaged in occupational safety and health programs. The ACGIH develops Threshold Limit Values (TLVs) for airborne concentrations of some 600 substances to assist in the control of health hazards.

TLVs represent concentration levels at which it is believed nearly all workers could be repeatedly exposed day after day without adverse effect. However, it is recognized that "a small percentage of workers may experience discomfort" under conditions at or below the TLV and that "a smaller percentage may be affected more seriously by aggravation of pre-existing conditions or by development of an occupational illness."

The ACGIH specifically cautions that the limits are not intended for other uses such as "evaluation of continuous uninterrupted exposure" or for evaluation of "community air pollution nuisances." The health criteria for some contaminants may be "protection against impairment of health," whereas "freedom from irritation, narcosis, nuisance or other forms of stress" may form the basis for other contaminant limits. However, the ACGIH Chemical Substance TLV Committee states that "... limits based on physical irritation should be considered no less binding than those based on physical impairment. There is increasing evidence that physical irritation may initiate, promote, or accelerate physical impairment through interaction with other chemical or biological agents."

There are three categories of TLVs. The first is a time-weighted average (TWA) and represents a concentration to which a worker could be continuously exposed during an 8-hour work day, 40 hours a week, over a normal working lifetime, without being adversely affected. The second is a short-term exposure limit (STEL)--a 15 minute time-weighted average concentration. The STEL is intended to supplement the TWA for cases in which a chemical has both acute and chronic toxic effects. STELs cannot be exceeded, and should not be sustained for longer than 15 minutes at a time and for no more than four times a day. In addition, there must be at least an hour between successive exposures to the STEL limit. The third category is a ceiling (TLV-C), which is a concentration that should never be exceeded when workers are present (ACGIH, 1988).

Summary Exhibits

The previous information is summarized in Exhibits 7-1, 7-2, and 7-3 (a and b). Exhibit 7-1 outlines the health protection goals of each standard and guideline; it also notes the typical setting to which each applies. Exhibit 7-2 describes each standard's target population group, the time periods for which the standards are set, and the number of substances covered. Exhibits 7-3 (a and b) compare the factors considered in establishing each standard and guideline.

7.2 COMPILATION OF STANDARDS

This section outlines existing standards for various substances observed in indoor air environments. The substances included are those covered by the existing public health standards and guidelines commonly applied to indoor air quality problems; included are six from EPA's NAAQS, 28 from the WHO Air Quality Guidelines for Europe, 35 from ASHRAE ventilation standards, and nine covered under the Canadian exposure guidelines (there is some overlap among those covered; hence, the total substances included number approximately 50). Where available, occupational standards, including OSHA PELs, NIOSH RELs, and ACGIH TLVs are included for comparison. The substances and relevant standards and guidelines are described in Exhibit 7-4, Sample Air Quality Standards and Guidelines.

As discussed in a later section, there is a shortfall between the number of known indoor air pollutants and the availability of public health exposure standards and guidelines that can be applied to each of these substances. Therefore, although there are hundreds of substances known to occur in indoor air environments, Exhibit 7-4 does not comprehensively address all known indoor air pollutants.

7.3 EVALUATION: SIGNIFICANCE OF EXISTING STANDARDS AND GUIDELINES

Several points emerge from the information outlining existing air quality health standards and guidelines. These include (1) differences between public health and occupational standards; and (2) major omissions among existing standards with regard to indoor air quality problems.

Differences Between Public Health and Occupational Standards

The most significant differences between various standards and guidelines are related to the differences between standards set to protect the general public versus those set to protect an occupational workforce. Public health standards (e.g., EPA NAAQS, WHO guidelines, Canadian exposure guidelines) are

Exhibit 7-1
General Health Protection Goals of Existing Air Quality Standards and Guidelines.

Type of Standard or Guideline	Agency	Standard/Guideline	Setting	Health Protection Criteria/Goals
Public Health	EPA	NAAQS	Any outdoor environment	Protect public health with an adequate margin of safety. Set so that even sensitive portions of the population should not be adversely affected.
	WHO	Air quality guidelines for Europe	Indoor and outdoor environments	"By 1995, all people of the [European] Region should be effectively protected against recognized health risks from air pollution."
	ASHRAE	Guideline	Indoor environments	Established so a substantial majority (usually 80%) of people exposed do not express dissatisfaction.
	Canada	Indoor air quality guidelines	Residences	Protect all exposed individuals, except those that might be "hypersensitive."
Occupational	OSHA	PELs	Workplaces in the United States	Insure that no worker shall suffer material impairment of health or functional capacity, to the extent feasible (assumes average American worker). Exposure assumptions are 8 hrs per day or 40 hrs per week over a normal working lifetime.
	NIOSH	RELs	Workplaces in the United States	Same as OSHA.
	ACGIH	TLVs	Workplaces in the United States	Protect "nearly all workers" (all healthy workers of working age and not particularly sensitive to pollutants). Exposure assumptions are 8 hours a day and/or 40 hours a week over a normal working life.

Exhibit 7-2

Comparison of Target Population, Time Periods, and Number of Substances Covered by Existing Air Quality Standards and Guidelines.

Type of Standard or Guideline	Agency	Standard/ Guideline	People to Whom Standard Applies	Time Periods Considered	Approx. Number of Substances	Notes
Public Health	EPA	NAAQS	American public (including sensitive portions of the populace)	1, 3, 8, 24 hrs, quarterly, annually	6	Standards are designed to protect primarily against ambient (outdoor) exposures.
	WHO	Air quality guidelines for Europe	General European public	Various	28	Guidelines are set assuming both indoor (nonindustrial settings) and outdoor exposures.
	ASHRAE	Concentration of concern	People in indoor environments	24 hrs 30 min	35	Uses various sources of preexisting standards and guidelines.
	Canada	Exposure guideline	General Canadian public	Various	9	Guidelines are set for residential exposure only and exclude radon.
Occupational	OSHA	PELs	American workers	8 hrs some ceilings	600	Process for regulating chemicals considers technological and economic feasibility.
	NIOSH	RELs	American workers	8 hrs some ceilings	150	Exposure limits are recommendations to OSHA and do not generally consider technological feasibility.
	ACGIH	TLV TLV-C TLV-STEL	American workers	8 hrs, 40 hrs/wk; ceiling (never to be exceeded); 15 min	600	390 of current 400 OSHA regulations are from 1968 ACGIH TLV list. Developed for workers in American settings but are used in other countries as well; updated annually.

Exhibit 7-3a

Comparison of the Factors Considered in Establishing Public Health Standards and Guidelines

Factors Considered When Adopting Existing Standards or Guidelines	**EPA/NAAQS**	**WHO Guidelines**	**ASHRAE Guidelines**	**Canada Guidelines**
Health Effects to be prevented	Long/short term	Long/short term	Long/short term	Long/short term
Population groups of concern	General public	General public	General public	General public
Population group targeted for protection	All including high risk groups	All including high risk groups	Substantial majority (80 %)	All including high risk groups
Number of substances covered	6	28	35	9
Exposure assumptions for which standards apply	Continuous/lifetime	Continuous/lifetime	Continuous/lifetime	Continuous/lifetime
Condition of cost or feasibility	No	No	Yes	Yes
Potential synergistic or additive effects	No	No[1]	No	No[2]

[1] WHO guidelines have been set for exposure to mixtures of sulfur dioxide and particulates.

[2] Additive effects for aldehydes are computed by formula.

Exhibit 7-3b

Comparison of the Factors Considered in Establishing Occupational Standards and Guidelines

Factors Considered When Adopting Existing Standards or Guidelines	**OSHA PELs**	**NIOSH RELs**	**ACGIH TLVs**	
Health Effects to be prevented		Long/short term	Long/short term	Long/short term
Population groups of concern	Workers	Workers	Workers	
Population group targeted for protection	All workers	All healthy workers	Nearly all healthy workers	
Number of substances covered	600	100	600	
Exposure assumptions for which standards apply	Indoor/work	Indoor/work	Indoor/work	
Condition of cost or feasibility	Yes	Yes	Yes	
Potential synergistic or additive effects	Yes[1]	No	Yes[1]	

[1] Limited to presumed additive effects addressed by formula (see text)

Exhibit 7-4

Sample Air Quality Standards and Guidelines

		Standard or Guideline ($m = mg/m^3$; $u = ug/m^3$)							
		Public Health				Occupational			
Substance	Averaging Time	EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	Comments
Acetone	24 hr			7m					
	8 hr					1800m		1780m	
	30 min			24m					
	15 min					2400m		2375m	
Acrolein	8 hr					250u		250u	
	15 min					800u		800u	
	Ceiling			25u					
Acrylonitrile	8 hr		*				461u		
	Ceiling						4610u		
Aldehyde (total)	1 hr				R<1				R = Sum (c_i/C_i) c_i = measured concentration C_i = 120u formaldehyde 50u acrolein 9000u acetaldehyde
Ammonia	Annual			0.5m					NIOSH ceiling is set for 5 minute exposure.
	8 hr					35m		18m	
	15 min					27m		27m	
	Ceiling			7m			34.8m		

continued

Exhibit 7-4 continued

Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline ($m = mg/m^3$; $u = ug/m^3$)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Arsenic	8 hr					500u		200u	
	Ceiling		*				2u		NIOSH ceiling is set for 15 minute exposure.
Asbestos	Annual		*						ACGIH levels (TWA) are amosite 0.5f/cc chrysotile 2.0f/cc crocidolite 0.2f/cc other 2.0f/cc f/cc = fibers per cubic cm NIOSH level for fibers over 5 um in length
	8 hr					various	100,000 f/m^3		
Benzene	8 hr		*			3.2m	0.32m		NIOSH ceiling is set for 15 minute exposure.
	Ceiling					16m	3.2m		
Beryllium	30 days			.01u					
	8 hr					2u		2u	
	30 min					5u			
	Ceiling					25u	0.5u		
Cadmium fume	Annual		.01-.02u						WHO guidelines are annual: 1-5 nanograms (rural areas) 10-20 nanograms (urban areas) OSHA standard is 100u(TWA) for cadmium fume, and 200u(TWA) for cadmium dust. ACGIH proposed TWA is 10u NIOSH recommends reducing exposure to lowest feasible level.
	24 hr			2u					
	8 hr					100u		50u	
	ceiling					300u			
Calcium oxide (lime)	continuous			.020-.030m					
	8 hr					5m			

Exhibit 7-4 continued

Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline (m = mg/m^3; u = ug/m^3)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Carbon disulfide	24 hr		.10m	.15m					WHO guideline of .02m is based sensory effects.
	10 hr						3m		
	8 hr					12m		30m	
	30 min		.02m	.45m					
	15 min					36m	30m		
Carbon dioxide	Continuous			1800m					
	Long term				6300m				
	10 hr						18,000m		
	8 hr					18000m		9000m	
	15 min					54000m		54000m	
	10 min						54,000m		
Carbon monoxide	8 hr	10m	10m	10m	9.9m	40m	40m	55m	WHO CO guidelines are designed to protect nonsmokers.
	1 hr	40m	30m		29m				
	30 min		60m						
	15 min		100m					440m	
	Maximum					229m	229m		
Chlordane	8 hr					0.5m		0.5m	
	Continuous			.005m					
	30 min							2m	
Chlorine	24 hr			.1m					ACGIH proposed guideline is 1.5m (8 hr) 3.0m (15 min) NIOSH 15 minute limit is a ceiling limit.
	8 hr					1.5m		3m	
	30 min			.3m					
	15 min							9m	
	Ceiling					3m	1.45m		

continued

Exhibit 7-4 continued
Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline (m = mg/m³; u = ug/m³)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Chromium	Annual		*						
	24 hr			.0015m					
	10 hr						0.001m		NIOSH 10 hour limit is for carcinogenic chromium; other chromiums have a 0.025 m 10 hour limit
	8 hr					.5m		.5m	
	15 min								
							0.05m		
Cresol	24 hr			.1m					
	10 hr						10m		
	8 hr					22m		22m	
1,2-dichloroethane (ethylene dichloride)	24 hr		0.7m	2m					
	8 hr					4m		40m	
	30 min			6m					
	15 min							1010m	
Ethyl acetate	24 hr			14m					
	8 hr					1400m		1400m	
	30 min			42m					
Formaldehyde	8 hr				(see aldehydes)				WHO level set to avoid complaints from sensitive people exposed in non-industrial indoor settings.
	24 hr								
	8 hr					1.2m(1ppm)		1.5m	
	1 hr								
	30 min		.1m						
	15 min					6m(5ppm)	0.12m	3m	NIOSH level reflects lowest reliably quantifiable concentration.
	Ceiling			.1m					

continued

Exhibit 7-4 continued
Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline ($m = mg/m^3$; $u = ug/m^3$)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Hydrochloric acid (hydrogen chloride)	24 hr			.4m					
	30 min			3m					
	Ceiling					7m		7m	
Hydrogen sulfide	24 hr		.15m	.04-.05m					
	8 hr					14m		14m	
	1 hr			.042m					
	30 min		.007m						WHO guideline of .007m is based on sensory effects.
	15 min					21m		21m	
	Ceiling						15m		NIOSH ceiling set for 10 minute exposure.
Lead	Annual		.5-1u						
	3 month	1.5u							
	24 hr			1.5u					
	10 hr						<100u		NIOSH limit set so workers' blood lead remains < 60ug/100g · blood.
	8 hr					50u		150u	
Manganese	Annual		.001m						WHO: short-term guideline desirable; but lack of data to set short-term limits.
	8 hr					1m		1m	
	15 min					3m			OSHA standard is for manganese fumes.
Mercaptans	1 hr			.02m					

continued

Exhibit 7-4 continued
Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline ($m = mg/m^3$; $u = ug/m^3$)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Mercury	Annual		1u						
	24 hr			2u					ACGIH and OSHA standard of 50u is for non-alkyl vapor, but is 10u (TWA) and 30u (STEL) for alkyl compounds. WHO guideline is for indoor air.
	8 hr					50u	50u	50u	
Methyl alcohol	24 hr			14m					
	10 hr						262m		
	8 hr					260m		260m	
	30 min			42m					
	15 min					310m	1048m	310m	
Methylene chloride (Dichloromethane)	Annual			20m					NIOSH recommends reducing exposure to lowest feasible limit.
	24 hr		3m	50m					
	8 hr					1740m		300m	
	15 min							1740m	
	Ceiling					3480m			
Microbial/biological contaminants									No formal guidelines/standards; ACGIH draft report states that concentrations exceeding 500 FCUs/m^3 require remedial action (see tex).
Nickel	Annual		*						
	24 hr			.002m					
	10 hr						0.015m		
	8 hr					.1m	.	.1m	OSHA and ACGIH standard is for soluble compounds.
Nitrogen dioxide	Long term				100u				
	Annual	100u		100u					
	24 hr		150u						
	8 hr							6000u	
	1 hr		400u		480u				
	15 min					1800u	1800u	10000u	

continued

Exhibit 7-4 continued
Sample Air Quality Standards and Guidelines

		Standard or Guideline ($m = mg/m^3$; $u = ug/m^3$)							
		Public Health				Occupational			
Substance	Averaging Time	EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	Comments
Nitrogen monoxide	24 hr			500u					
	10 hr						30,000u		
	30 min			1000u					
Nitrogen oxides	24 hr		150u						
	1 hr		400u						
Ozone	Continuous			100u					
	8 hr		100-120u			200u		200u	ASHRAE standard is for indoor sources only.
	1 hr	235u	150-200u		240u				
	15 min					600u		600u	
Particulates (PM-10)	Annual	50u							
	24 hr	150u							
Particulates (PM-2.5)	Long term				40u				
	8 hr						500u		
	1 hr				100u				

continued

Exhibit 7-4 continued

Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline (m = mg/m^3; u = ug/m^3)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Phenol	24 hr			.1m					
	10 hr						20m		
	8 hr					19m		19m	
	15 min						60m		
Polynuclear aromatic hydrocarbons (carcinogenic fraction)			*						ACGIH standard for coal tar pitch volatiles (benzene solubles) is 0.2m (TWA).
Radon	Annual	.02WL	.013WL	.027WL					WL = working level; one WL is approximately equivalent to 200 picocuries per liter (PCi/l). EPA recommends that mitigation be undertaken in homes with levels above 4PCi/l (.02WL). WHO: recommended level for remedial action in buildings is > 100 Bq/m^3.
Styrene	24 hr		.80m						WHO 30 minute guideline is based on odor detection.
	10 hr						213m		
	8 hr					215m		215m	
	30 min		.07m						
	15 min					425m		425m	
	Ceiling						426m		
Sulfates	Annual			4u					
	24 hr			12u					

continued

Exhibit 7-4 continued
Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline ($m = mg/m^3$; $u = ug/m^3$)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Sulfur dioxide	Long term				50u				
	Annual	80u		0u					
	24 hr	365u		65u					
	10 hr						1300u		
	8 hr					5000u		5000u	
	1 hr		350u						
	15 min					10000u		10000u	
	10 min		500u						
	5 min				1000u				
Sulfuric acid	Annual			.05m					WHO: more data needed; however, repeated exposure at or above .01 mg/m^3 is cause for concern.
	10 hr						1m		
	8 hr					1m		1m	
Tetrachloroethylene (perchloroethylene)	24 hr		5m						NIOSH recommends minimizing workplace exposure and limiting number of exposed workers WHO guideline of 8m is based on sensory effects.
	8 hr					170m		335m	
	30 min		8m						
	15 min							1340m	
Toluene	24 hr		8m						WHO guideline of 1 is based on sensory effects.
	8 hr					375m	375m	375m	
	30 min		1m						
	15 min					560m		560m	
	10 min						750m		

continued

Exhibit 7-4 continued
Sample Air Quality Standards and Guidelines

Substance	Averaging Time	Standard or Guideline ($m = mg/m^3$; $u = ug/m^3$)							Comments
		Public Health				Occupational			
		EPA	WHO	ASHRAE	Canada	OSHA	NIOSH	ACGIH	
Trichloroethylene	Annual			2m					
	24 hr		1m	5m					
	10 hr						4.6m		
	8 hr					270m		270m	
	30 min			16m					
	15 min					1080m		1080m	
Vanadium	Annual								
	24 hr		1u	2u					
	10 hr						1000u		
	8 hr					50u			
	15 min						50u		OSHA standard is for vanadium respirable dust or fumes. NIOSH 10 hour limit set for metallic vanadium and vanadium carbide.
Vinyl chloride	Annual		*						
	8 hr					2.6m		10m	
	1 hr								NIOSH recommends limiting exposure to lowest reliably detectable level.
	15 min					12.8m			
Water vapor (relative humidity)				20-60%	30-70% summer 30-55% winter				
Zinc	Annual			50u					NIOSH limits are for zinc oxide.
	24 hr			100u					
	10 hr						5000u		
	8 hr					10,000u			OSHA limit is for zinc oxide total dust. Limit for respirable fraction is 5,000u.
	15 min						15,000u		

continued

Exhibit 7-4 concluded

Sample Air Quality Standards and Guidelines

Notes

Reported values were converted where necessary so that all values for the same chemical are in the same units to facilitate comparisons. Canadian standards distinguish between short term or long term exposures. Short term exposures are listed as 1 hr exposures in this table.

Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
EPA	Environmental Protection Agency
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
WHO	World Health Organization

Sources

ACGIH, Threshold Limit Values and Biological Exposure Indices for 1987-88.
ASHRAE Standard 62-1981, Ventilation for Acceptable Indoor Air Quality.
Environmental Health Directorate, Canada, Exposure Guidelines for Residential Indoor Air Quality, July 1986.
NIOSH, 1986. NIOSH recommendations for occupational safety and health standards. Morbidity and Mortality Weekly Report, 35(1S).
OSHA Standards for Air Contaminants, 29 CFR Part 1910.1000.
WHO, 1987. Air Quality Guidelines for Europe. World Health Organization Regional Office for Europe, Copenhagen. WHO Regional Publications, European Series No. 23. 1987.

* WHO does not establish guidelines for these substances; instead, the agency publishes risk factors for each substance to indicate potential human health risks per unit of exposure.

generally one to two orders of magnitude lower (more protective) than occupational standards (e.g., those set by OSHA, NIOSH, and ACGIH). These differences occur for both short- and long-term exposure limits. Several reasons account for these differences; the most important are:

- Public health standards include protection for the old, young, pregnant women, those with preexisting respiratory ailments, and other sensitive population subgroups; occupational standards typically presume a healthy adult workforce, and may explicitly accept that a very small percentage of the workforce will experience adverse health effects at the occupational exposure limit;

- Public health standards generally assume continuous exposures (24 hours per day, over a 70-year lifetime); occupational standards are realistically based on an 8-hour exposure periods for no more than 40 hours per week.

- Public health standards are usually established with health concerns as the sole criteria; occupational limits may be established in consideration of the technical and economic feasibility of their implementation (e.g., OSHA permissible exposure limits);

- Implicit in occupational standards is the assumption that exposure is voluntary (inherent in the chosen occupation), whereas public health standards generally assume exposures to be involuntary.

Notwithstanding these differences, some organizations apply occupational standards to public health problems because of the limited number of available public health standards or guidelines. Fewer than 60 of the hundreds of known chemical contaminants found indoors are covered by public health standards or guidelines. By comparison, occupational guidelines have been established for hundreds of substances (e.g., the ACGIH and OSHA have established standards for approximately 600 substances). Some organizations apply these occupational guidelines to public health problems by lowering the occupational limits with a "safety" or "protection" factor (e.g., dividing the ACGIH threshold limit values by a factor of 10 or 100).

Major Omissions Among Existing Standards with Regard to Indoor Air Quality Problems

Two areas of particular concern to indoor air quality problems have yet to be adequately addressed by existing standards and guidelines. These include exposure to pollutant mixtures and to biological contaminants (e.g., molds, fungi, mites, bacteria, and viruses).

Pollutant Mixtures

The effects of exposure to more than one contaminant, i.e., to mixtures, in indoor air is an important issue since the typical indoor environment contains multiple contaminants. Effects from mixtures may be synergistic, antagonistic, or additive. A synergistic reaction results in a total effect that is more than the sum of the individual effects; an antagonistic effect results when the combined effect is less than the sum of the individual effects.

One example of the threats from multipollutant exposure is a potential adverse reaction from an excessive "total contaminant body burden." The total body burden concept implies that exposure even to low pollutant concentrations can "add up" to a toxicity level that can trigger an adverse reaction known as "environmental maladaptations syndrome," with adverse effects on muscle tissue, mucous membranes, and respiratory, vascular, and other biological systems (Repace, 1982).

Given the complexity of possible synergistic reactions, and the fact that knowledge about them is rudimentary, guidelines for mixtures based on synergistic effects are rare, and an adequate way to address pollutant mixtures has yet to be developed. One approach is simply to treat pollutant mixtures on an additive basis. For example, ACGIH and OSHA recommend an additive approach for exposures to mixtures when the components have similar toxicological effects. The equivalent exposure for the mixture is calculated as:

$$E_m = C_i/T_i + C_2/T_2 + \cdot \cdot \cdot C_n/T_n$$

where E_m is the equivalent exposure to the mixture, C_i is the concentration and T_i is the standard (e.g., TLV) for the "ith" pollutant. Exposure to the mixture violates the standard if E_m exceeds 1. The allowed exposure to any individual contaminant is reduced as exposures to concentrations of others in the mixture are accounted for.

Other preliminary approaches under development would establish exposure guidelines for combinations of volatile organic compounds (VOCs). These approaches are based on studies indicating when acute human health effects (such as those associated with sick building syndrome) are likely to occur. Research has so far indicated that total VOC concentrations below 0.16 mg/m^3 will not cause acute effects, while total VOC concentrations above 5.0 mg/m^3 are found to generate acute effects (Molhave, 1984). Partly on the basis of these findings, some investigators recommend an action level of 1.0 ppm total

VOC as an indicator of indoor air quality problems (Gammage and Kerbel, 1987). (1.0 ppm VOC is approximately 5 mg/m^3 total VOC assuming an average molecular weight of 100).

Biological Contaminants

Existing standards and guidelines do not address biological (or "microbial") contaminants, yet biological contaminants pose significant indoor air quality problems.

Several reports have documented numerous indoor microbial contaminants (e.g., Sexton, 1986; Morey et al., 1986; Blumenthal et al., 1987). Measured health effects from research and case studies will help to establish indoor air quality standards for biological contaminants. For example, one study noted that 28 percent of workers develop coughing and shortness of breath when exposed to 27,000 spores/m^3 of Aspergillus fumigatus (Solomon and Burge, 1984). Another report notes that "most mite allergic patients will record symptoms either of rhinitis or asthma" at 10 ug of allergen per gram of dust.

Recently, efforts have been made to develop biological contaminant guidelines. For example, a report of the ACGIH Committee on Bioaerosols suggests that indoor levels of saprophytic bioaerosols should be less than one-third of outdoor levels where outdoor air is the only source and should be qualitatively similar (Burge et al., 1987). The report, however, provides guidance on measurement methods, interpretation of data, and remedial actions but does not recommend specific guidelines for acceptable exposure.

In reporting on a recent study of fungi in 50 Canadian houses, Miller et al. propose the following criteria of acceptability for fungal pollution in indoor air (Miller et al. 1988, as reported in Walkinshaw, 1988):

- The presence of certain pathogens (such as A. fumigatus) and certain toxigenic fungi (such as S. atra) should be considered as unacceptable.
- More than 50 CFU/m^3 should be reason for concern if there is only one species present.
- Less than 150 CFU/m^3 should be considered acceptable if there is a mixture of species.
- Less than 300 CFU/m^3 should be considered as acceptable if the species present are primarily Cladosporium or other common phylloplane fungi.

[illegible] Pollutant Guidelines

[illegible]

[illegible] combustion appliances which differ from the ambient [illegible] standards. The levels for carbon monoxide are [illegible] to the [illegible] by time weighted averages for long-term exposure [illegible] as a peak limit [illegible] carbon monoxide which is used for [illegible] (ASHRAE, 1981).

In addition, the National Academy of Sciences has developed exposure limits for military and space environments. The United Nations' International Labour Organization (ILO) has developed [illegible] exposure guidelines, and several [illegible] have established exposure limits for specific indoor pollutants (particularly formaldehyde). Moreover, [illegible] of public health, ambient air quality standards. Exhibit 7-5 provides examples of ambient air quality standards for [illegible] substances set by various countries around the world. These are general air quality standards. They have not [illegible] for, or applied to, indoor air quality problems.

7.3 VENTILATION STANDARDS

Building ventilation rates [illegible] of indoor air quality. ASHRAE Standard [illegible] ventilation rate procedure for [illegible] specifies minimum ventilation rates for [illegible] types of indoor spaces. Mandatory ventilation provisions of model building codes, typically based on ASHRAE's ventilation requirements, are part of many local building codes. The U.S. Department of Housing and Urban Development (HUD) Minimum Property Standards and manufactured housing construction specifications also contain ventilation requirements for [illegible] subject to HUD regulations.

ASHRAE Standard 62-1981

ASHRAE 62-1981R, the public review draft of an update revision to Standard 62-1981, specifies a ventilation rate of twenty cubic feet per minute (cfm) per person for office environments (ASHRAE, 1986). Exhibit 7-6 presents the ventilation requirements for a portion of the commercial, institutional and residential indoor spaces specified in the standard. In order for ventilation at these rates to provide

Exhibit 7-5

Sample Air Quality Standards from other Countries.[1]

Substance	Standard (for averaging time noted)			Country	Comments
	30 minutes	24 hours	12 months		
Benzene	0.2	0.1	0.025	Poland	protected zones
	10	03	0043	Poland	specially protected zones
	0.3	01		DRG	Democratic Republic of Germany
	08			Hungary	specially protected zones
	1.5	0.8		Hungary, USSR	protected zones
	2.4	0.8		Romania	
Formaldehyde	0.012			Hungary	specially protected zones
	0.03	0.01		Romania	
	0.035	0.012		Hungary, DRG	protected zones
	0.05	0.035		Czechoslovakia	
	0.07	0.03		Hungary	(other than protected or specially protected zones)
Sulfur dioxide	0.07	0.05		Austria	99th percentile for summer months
	0.11			Yugoslavia	
	0.14			FRG	Federal Republic of Germany
	0.5	0.005		USSR	
	0.5	0.05		Bulgaria	
	0.72	0.3		Finland	
	0.75			Denmark	
		0.4	0.15	Spain	
		0.25		Netherlands	98th percentile of values/year
		0.08		Italy	
		0.15		Turkey, New Zealand	
Trichloroethylene	1.0			Hungary	specially protected zones
	4.0	1.0		Hungary, DRG	protected zones
	50	30		Hungary	(other than protected or specially protected zones)
Vinyl chloride	0.4	0.2		DRG	
Zinc oxide		0.05		USSR	

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[1] Concentrations in mg/m^3

SOURCE: Bouscaren et al., 1986 (note that Bouscaren et al. list standards for more than 140 substances; this list exemplifies the wide variety of standards set by various nations).

Exhibit 7-[illegible]

ASHRAE Standard 62-[illegible] Outdoor Air Requirements for Ventilation a/

	cfm/person	l/s/person
Commercial Facilities		
Office Space	20	10
Reception Areas	15	8
Conference Rooms	20	10
Hotel Bedrooms (cfm/room)	30 b/	15 b/
Dry Cleaners	30	15
Supermarkets	15	8
Theater Auditoriums	15	8
Educational Facilities		
Classrooms	15	8
Laboratories	20	10
Libraries	15	8
Institutional Facilities		
Hospital Patient Rooms	25	13
Hospital Medical Procedure Rooms	15	8
Hospital Operating Rooms	30	15
Correctional Facility Cells	20	10
Correctional Facility Dining Halls	15	8
Residential Facilities		
Living Areas	15	7.5
Kitchens	100 c/	50 c/
Garages	100 d/	50 d/

a/ Source: ASHRAE 1986.

b/ Units are per room.

c/ Units are per room with intermittent mechanical exhaust.

d/ Units are per car.

adequate indoor air quality, the procedure sets requirements for supply air of acceptable quality and assumes that ventilation system design and operation remove contaminants from the occupied zone at least as effectively as would be accomplished by complete mixing in the occupied zone (ASHRAE, 1986).

Ventilation Requirements in Model Codes

Building Officials and Code Administrators International (BOCA), the Southern Building Code Congress International (SBCCI), the Council of American Building Officials (CABO), and other code writing organizations often incorporate ventilation requirements into their model codes (NIBS, 1986). For example, the BOCA Basic/National Mechanical Code specifies ventilation rates dependent on occupancy similar to ASHRAE 62-1981, but at generally lower rates. Similarly, the CABO One and Two-Family Dwelling Code requires air exchange rates of 0.5 per hour for general living areas and 5.0 per hour for bathrooms with mechanical ventilation.

HUD Ventilation Requirements

HUD incorporates ventilation requirements into its minimum property standards for residences constructed in its mortgage insurance and low-rent public housing program and in construction requirements for manufactured housing (U.S. HUD, 1986a; U.S. HUD, 1986b). The ventilation requirements for manufactured housing construction specify that an area equivalent to not less than four percent of the floor area must be provided for natural ventilation, or, alternatively, that a mechanical system capable of changing room air every thirty minutes be present. Bathroom and toilet compartments require either one and one-half square feet of openable glazed area or a mechanical system capable of producing five air changes per hour. Manufactured housing construction requirements also specify venting of combustion appliances and require that purchasers are presented with options to improve overall ventilation.

Limitations on the Effectiveness of Ventilation Standards to Achieving Acceptable Indoor Air Quality

Prescribing ventilation standards in the design of new buildings is an extremely important element in an overall strategy to control and mitigate indoor air quality problems. Ventilation standards do not guarantee adequate indoor air quality and several limitations to such standards are addressed below. These include the indirect nature of ventilation control, ventilation efficiency problems, operational compromises to design standards, and procedural limitations of the ASHRAE Standard 62-1981.

Ventilation as an Indirect Control Method

Ventilation improves indoor air quality by diluting indoor air with outdoor air. It is a strategy which is not targeted to any individual pollutant or source, and there is therefore a limit on the extent to which ventilation can be relied on to adequately mitigate all pollutants, particularly in the presence of strong sources. For example, an outdoor air ventilation rate of 250 cfm per occupant would be necessary to adequately protect occupants from cancer risk due to environmental tobacco smoke (Repace and Lowrey, 1985). Nevertheless, ventilation can be very effective in mitigating problems associated with low or moderate levels of large numbers of environmental contaminants emanating from multiple sources throughout a building. Thus, ventilation has a critical role in the overall strategy to control indoor air pollution which may also include source control and air cleaning mitigation methods.

Ventilation Efficiency

Even if the outdoor air ventilation rates are delivered into the building, they may not be sufficiently distributed to individual work areas, or to the breathing zone of occupants in those areas. Thus, an overall assessment of the distribution of ventilation air to occupant work areas is an appropriate adjunct to determining whether ventilation rates are adequate or whether they comply with indoor air quality ventilation standards.

Design verses Operational Application of Standards

ASHRAE ventilation standards, and standards which are contained in some building codes, are most often applied to the design of new and renovated buildings. Standards appropriate to building use should also be applied during the normal operation of existing buildings, but this is often not the case. In fact, most building codes do not require that ventilation systems even be turned on.

Investigations of indoor air quality complaints in problem buildings reveal that the ventilation system in many of these problem buildings do not perform according to design standards. This may be due to inadequate maintenance, changes in building occupancy which can increase requirements above original design loads, reduced operation for energy conservation purposes, or lack of appreciation or understanding of operators with the design logic of the system. Thus, while design standards may be adequate, subsequent operation and maintenance of the system will often compromise those standards and reduce their potential to control indoor air quality.

Procedural and Other Issues with ASHRAE 62-1981

ASHRAE Standard 62-1981 and its most recent revised draft, ASHRAE 62-1981R, contain a ventilation procedure and an indoor air quality procedure. The indoor air quality procedure may be used as an alternative to the ventilation procedure and would allow the user to reduce outdoor ventilation rates to any level determined to provide acceptable indoor air quality, based on guidance given in the standard.

While this concept makes sense theoretically, EPA believes that in practice, the lack of adequate criteria to predict the acceptability of the building's indoor air has the potential to render the standard ineffective when minimum ventilation rates prescribed in the standard are not met in the design of the ventilation system.

7.5 SUMMARY

Approximately 50 public health standards and guidelines are currently applied to indoor air quality situations. These standards cover a small fraction of the hundreds of individual pollutants known to occur in indoor environments, and they fail to comprehensively address problems involving pollutant mixtures or biological contaminants. Notwithstanding these difficulties, important steps are under way to improve the application of air quality standards to indoor settings. Among these are the recent publication of World Health Organization guidelines that explicitly consider indoor exposures, and research involving pollutant mixtures and biological contaminants. However, important information gaps still persist. Information is sparse concerning (1) mixtures and biological pollutants, and (2) the effects of using safety factors in the application of occupational standards to public health problem settings.

Minimum ventilation rates provide an important element in an overall strategy to control indoor air quality. ASHRAE Standard 62-1981R provides a comprehensive list of outdoor air ventilation rates for a variety of indoor spaces. In addition, ventilation requirements are contained in some building codes, and in requirements for the construction of housing under programs administered by the Department of Housing and Urban Development. Use of ventilation standards as a method of controlling indoor air pollution is important, but it's potential in controlling indoor air quality is constrained by both technical and institutional limitations.

REFERENCES

American Conference of Government Industrial Hygienists (ACGIH). 1988. TLVs: Threshold Limit Values and Biological Exposure Indices for 1988-1989. American Conference of Governmental Industrial Hygienists.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 1981. ASHRAE Standard 62-1981. Ventilation for Acceptable Indoor Air Quality. Atlanta, Ga.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 1986. ANSI/ASHRAE 62-1981R. A Proposed American National Standard: Ventilation for Acceptable Indoor Air Quality. Public Review Draft. Atlanta, Ga.

Blumenthal, M., B. Roitman-Johnson, R. Sigford, and A. Streifel. 1987. Indoor Aeroallergens: Measurement and Their Clinical Significance. Presented at the 80th Annual Meeting of the Air Pollution Control Association, New York, 21-26 June 1987.

Bouscaren, R., M. J. Brun, A.C. Stern, and R. Wunenburger. 1986. Air Pollution Standards. Chapter 5 in Stern, A.C. 1986. Air Pollution. Third edition, Volume VIII. Supplement to Management of Air Quality. Academic Press, Orlando.

Burge, Harriet A., et al., 1987. Bioaerosols: Guidelines for assessment and sampling of saprophytic bioaerosols in the indoor environment. A report of the Bioaerosols Committee of the ACGIH. Applied Industrial Hygiene. September.

Environmental Health Directorate. 1986. Exposure guidelines for Residential Indoor Air Quality (Excluding Radon). A Report of the Canadian Federal-Provincial Advisory Committee on Environmental and Occupational Health, Environmental Health Directorate, Health Protection Branch. Office of the Minister of National Health and Welfare. July 1986.

Environmental Protection Agency. 1977. Air Quality Criteria for Lead. Office of Research and Development, U.S. Environmental Protection Agency (EPA-600/8-77-017).

Environmental Protection Agency. 1980. Air Quality Criteria for Particulate Matter and Sulfur Oxides; Volume 1, Summary and Conclusions. Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency (External Review Draft No. 1).

Gammage, R.B., and W.S. Kerbel. 1987. American Industrial Hygiene Association, Indoor Environmental Quality Reference Manual. Proc. Fourth International Conference on Indoor Air Quality and Climate, 17-21 August 1987, West Berlin.

HUD. 1986a. Minimum Property Standards. Part 200. Subpart S. Code of Federal Regulations, Title 24, Sections 200.925 and 200.926.

HUD. 1986b. Manufactured Home Construction and Safety Standards. Part 3280. Code of Federal Regulations, Title 24, Sections 3280.103 and 3280.710.

Molhave, L. 1984. Volatile organic compounds as Indoor Air Pollutants. In Indoor Air and Human Health, R.B. Gammage and S.V. Kaye, eds. (1985), Lewis Publishers, Chelsea, Michigan.

Morey, P.R., J.L. Clere, W.G. Jones, and W.G. Sorenson. 1986. Managing Indoor Air for Health and Energy Conservation. Proc. IAQ '86 for the American Society of Heating, Refrigerating and Air-Conditioning Engineers, 20-23 April 1986, Atlanta, Georgia.

Miller, J.D., P., Laflamme, A.M., Sobol, Y., Lafontaine, and Greenhalgh. 1988. Fungi and Fungal Products in Some Canadian Houses, International Biodeterioration, in press. (As reported in Walkinshaw, 1988).

NIBS. 1986. Standards, Regulations, and Other Technical Criteria Related to Indoor Air Quality. National Institute of Building Sciences. Washington, D.C.

NIOSH. 1988. NIOSH Recommendations for Occupational Safety and Health Standards 1988, Atlanta, 1988.

Repace, J.L. 1982. Indoor air pollution. Environ. Int., 8:21-36.

Repace, & Lowrey. 1985. An Indoor Air Quality Standard for Ambient Tobacco Smoke based on Carcinogenic Risk. New York State Journal of Medicine, Vol. 85.

Sexton, K. 1986. Indoor Air Quality: An Overview of Policy and Regulatory Issues. Science, Technology, and Human Values, 11(1):53-67, Winter 1986.

Solomon, W., and H. Burge. 1984. Allergens and Pathogens. In Indoor Air Quality, CRC Press.

Walkinshaw, D.S. 1988. Canadian Indoor Air Quality Standards, Guidelines and Research Activities. In Indoor and Ambient Air Quality, R. Perry and P. W. Kirk eds., Selper Ltd., London.

WHO. 1987. Air Quality Guidelines for Europe. World Health Organization, Regional Office for Europe, Copenhagen. WHO Regional Publications, European Series, No. 23.

CHAPTER 8 - FEDERAL AUTHORITIES APPLICABLE TO INDOOR AIR

This chapter covers the Federal laws which address various aspects of indoor air quality. Except for the National Environmental Policy Act, whose requirements affect all federal agencies, the laws are grouped according to the Agency with the primary role in implementing their provisions. Aspects of the laws which relate to indoor air quality are summarized in Exhibit 8-1.

8.1 NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act (42 USC 4331 et seq.) established a national goal to "assure for all Americans, safe, healthful, productive, and aesthetically and culturally pleasing surroundings" and, required that all agencies of the Federal government (1) develop procedures to insure that "presently unquantified environmental amenities and values may be given appropriate consideration in decision-making..." and (2) develop an environmental impact statement for any major Federal action "significantly affecting the quality of the human environment". The policies and goals set forth in this Act are to be "supplementary to those set forth in existing authorizations." While not specific to indoor air, this broad overarching legislation provides a context for the consideration of indoor air quality and other environmental concerns in all major Federal actions taken pursuant to other authorities.

8.2 ENVIRONMENTAL PROTECTION AGENCY (EPA)

The Environmental Protection Agency was established in 1970 under Reorganization Plan No. 3 (42 USC 4321) in which the environmental pollution control functions of several federal agencies were consolidated. The general roles and functions given to EPA under Reorganization Plan No. 3 were to (1) establish and enforce environmental protection standards, (2) research the effects and controls of environmental pollution, and (3) provide grants and technical assistance to others as a means of arresting environmental pollution. Legislation with specific authorities relevant to indoor air includes the Clean Air Act; the Toxic Substances Control Act; the Federal Insecticide, Fungicide, and Rodenticide Control Act; the Safe Drinking Water Act; [illegible] Superfund Amendments and Reauthorization [illegible]

[illegible] et seq.) is the legal basis [illegible] in the United States. [illegible] enhance the quality of the [illegible] to protect the public health and the [illegible] of the population." Progress toward this [illegible]

Exhibit [illegible]
[illegible] of Regulatory Authority by Agency, Statute, and Activity

Type and Level of Authority

[illegible]	Regulations	Standards	[illegible]	Enforcement	Demonstration of Technology	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

goal is accomplished through a complex program involving a close partnership between EPA and the states.

The Clean Air Act provides EPA with regulatory authority to establish standards for two categories of air pollutants:

> Criteria pollutants are pollutants which can reasonably be expected to "endanger public health or welfare" and the presence of which result from "numerous and diverse mobile or stationary sources." In response to the potential threat posed by these agents, EPA establishes National Ambient Air Quality Standards (NAAQS). States are required to develop State Implementation Plans (SIPs) designed to meet those standards. There currently are NAAQS for six criteria pollutants: inhalable particulate matter (≤10 micron diameter), sulfur oxides, nitrogen dioxide, ozone, carbon monoxide, and lead.
>
> **Hazardous pollutants** are those which "may reasonably be anticipated to result in an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness." EPA formally "lists" pollutants as hazardous and then promulgates national emission standards for significant source categories of the designated substances; these emissions limits are called National Emissions Standards for Hazardous Air Pollutants (NESHAPS). Eight pollutants have been listed as hazardous: mercury, beryllium, asbestos, vinyl chloride, benzene, radionuclides, inorganic arsenic compounds, and coke oven emissions.

The CAA gives EPA authority to regulate air pollutants. However, the overall structure and terminology of the Act -- in particular the scale on which it defines air pollution problems and prescribes solutions-- indicate that Congress conceived of air pollution as an outdoor phenomenon and contemplated regulation only of the outdoor air.

The heart of the statutory scheme is a nationwide system of ambient air quality standards and area-wide approaches to implementation through intra- and inter-state planning and controls. The Act thus creates a regulatory structure that treats air pollution as a large-scale problem that begins, for example, with the "emission" or "discharge" of pollutants from "any building, structure, facility or installation" into the "atmosphere" or "ambient air."

The Act considers that air pollution may have impacts across state and international boundaries. In addition, the Act directs EPA to monitor air quality "in major urban areas and other appropriate areas throughout the United States" and thus appears to be directed to outdoor rather than indoor pollution. This focus on outdoor pollution appears also in the legislative history where Congress voiced concern about "the air over most cities and towns". Consistent with this view, EPA regulations adopted in 1971 defined "ambient air" for certain purposes to mean air "external" to buildings and other structures (40 CFR 50.1(e)).

In summary, the Clean Air Act confers general responsibility to EPA to protect the public health and welfare from air pollution, but its structure and provisions direct EPA to control air pollution outdoors.

Toxic Substances Control Act (TSCA)

Congressional intent as stated in TSCA is the development by the manufacturers and processors of "adequate data...with respect to the effect of chemical substances and mixtures on health and the environment..." and "adequate authority...to regulate chemical substances and mixtures which present an unreasonable risk of injury to health and the environment..." (15 USC 2601). The statute grants to the Administrator the authority to require testing of suspect chemicals, and to establish rules and schedules for performing those tests. An advisory committee can recommend priority chemicals to the Administrator for which rules should be developed. In addition, manufacturers and processors can petition the Agency to develop test standards for a chemical of interest.

The most important data gathering authorities of TSCA are as follows:

- Section 4 of TSCA was included to develop data that would be useful in assessing the potential risks from existing chemicals. In order to require testing, EPA must determine that there are insufficient data about the effects of the chemical, and that testing is needed to develop these data. The testing that can be required for a chemical depends on the findings made and the data already available. Health tests may include: acute, subchronic, reproductive and developmental toxicity, neurotoxicity, skin sensitization, mutagenicity, pharmacokinetics, and carcinogenicity. Testing to determine exposures to a chemical or the fate of the chemical may also be obtained.

  Several offices in EPA have or are using Section 4 to gather data to support their programs. This could also be a useful tool in supplementing data on indoor air. Chemicals may be referred by the Interagency Testing Committee, which consists of representatives from other governmental agencies, such as, the OSHA. These agencies also provide testing recommendations of relevance to their Agency needs.

- o Section 8 (Reporting and Retention of Information)
  - Section 8(a) gives EPA the authority to promulgate rules to collect existing use, production and exposure data on specific chemicals. EPA has promulgated rules under the authority of Section 8(a) which provide a mechanism for collecting basic information on the manufacture, processing, and use of chemicals.
  - Section 8(b) requires EPA to keep a current inventory of chemicals manufactured and processed in the U.S. originally published in 1977, the inventory currently contains approximately 15,000 chemicals.
  - Section 8(d) allows EPA to collect unpublished health and safety studies and related information on selected chemicals.
  - Section 8(e) requires industry to report information to EPA that indicates a chemical may present a substantial risk. Information is continually being received under this provision.

TSCA also authorizes EPA to consult with the Secretary of Health and Human Services in conducting research, development, and necessary monitoring.

In addition to data gathering, TSCA has provisions that enable EPA to control exposure to chemicals that present or may present an "unreasonable risk or injury to human health or the environment". The Act provides EPA with authority to impose a variety of regulatory sanctions. However, before issuing a regulation, EPA must weigh the reduction in risk attributable to the regulation against the regulatory burdens to society, including costs. Further, EPA must use the "least burdensome" sanction, taking into account whether the health threat could be eliminated or reduced to a sufficient extent under other Federal statutes. Potential sanctions which could be applied include the following (15 USC 2605):

- o prohibit or limit the manufacture, processing, or distribution of the chemical;
- o require the chemical to be marked with warnings and instructions;
- o require the manufacturers and processors to monitor or conduct tests of the manufacturing and processing procedures;

- prohibit or regulate commercial use or disposal;
- require public notice of the health risk, and require replacement or refunds; and
- require revision of manufacturing quality control standards.

Regulations adopted by EPA pursuant to its authority under TSCA are found in Subchapter R of Title 40 of the Code of Federal Regulations.

In summary, with some restrictions, TSCA provides EPA with the ability to restrict the manufacture, distribution, and use of toxic chemical agents, including any that may be significant indoor air pollutants.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

One of the primary purposes of FIFRA is to ensure that the use of pesticides, when applied in accordance with EPA-approved label directions, will not cause "unreasonable adverse effects" (as defined in the Act) to humans or the environment. In some respects, FIFRA is similar to TSCA, in that it provides EPA with authority to require the submission of chemical-specific data, and to restrict the distribution and use of the chemicals which lie within its statutory domain. Although pesticides are commonly thought of in the context of agriculture, they are widely used throughout our society for a variety of purposes, both indoors and out. Regardless of the locus of its use, any pesticide (as defined in FIFRA section 2(u)) is subject to regulation under FIFRA.

- Section 3(a) prohibits any person from selling, distributing, or holding any pesticide which is not registered by the Agency. FIFRA section 3(c)(5) requires EPA to register a pesticide upon a determination that (among other things) its use in accordance with labeled directions will not cause "unreasonable adverse effects." FIFRA section 2(bb) defines this latter term as: "...any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide." Upon a determination that a pesticide cannot otherwise meet the "3(c)(5)" criteria for registration, EPA may classify that product as a "restricted-use" pesticide, thereby limiting its use to certified applicators, or persons under the certified applicator's direct supervision...the rationale being that trained applicators are more conscientious about following label directions and precautions.

information [illegible] health and safety hazards of asbestos; determine [illegible] sampling and testing asbestos containing materials [illegible] review the EPA [illegible] standards [illegible] formulating

Safe Drinking Water Act (SDWA)

The Safe Drinking Water Act (42 USC [illegible] et seq) authorizes EPA to conduct research [illegible] frequency and effects of contaminants [illegible] Contaminants found in the water supply [illegible] the community may affect the indoor air quality of the households and businesses being served. Radon, for example, [illegible] groundwater serving a house or community, or the water may contain volatile organic compounds. These pollutants may be introduced into the building by aerosolization from showers or other uses of the water.

The authority of the Administrator under the SDWA includes the establishment of primary and secondary regulations to protect the safety of public water systems. The regulation of constituents that may degrade indoor air quality are peripheral to the intent of the [illegible] regulations are to apply to contaminants which may have any adverse effect on the health of persons" (42 USC 300f (1)(B)). The Act therefore provides clear authority to set standards for indoor air pollutants that originate in the public water supply.

SARA Title IV (Radon Gas and Indoor Air Quality Research Act)

[illegible] EPA [illegible] research program for [illegible] indoor air quality. The purpose of [illegible] program [illegible] to gather information [illegible] aspects of indoor air [illegible] sector [illegible] to mitigate [illegible] specified [illegible]

[illegible]

The Act requires EPA to establish advisory [illegible] submit an implementation plan within 90 days [illegible] report with recommendations within 2 years after [illegible] implementation [illegible] submitted to Congress [illegible]

In summary, [illegible] provides [illegible] conduct research [illegible] activities [illegible] sectors, and disseminate information on indoor [illegible] provides no [illegible] standard [illegible]

In addition [illegible] IV, section 118[illegible] provides authority [illegible] Administrator to conduct [illegible] assessment of the locations and risks from radon [illegible] demonstrations of control techniques, and the dissemination [illegible] public information.

8.3 DEPARTMENT OF ENERGY (DOE)

The Department of Energy is responsible [illegible] of federal energy-related programs. These responsibilities [illegible] include co[illegible] conservation [illegible] and conducting a comprehensive [illegible] research and [illegible]. Given the [illegible] energy sources [illegible] production, and [illegible] conservation in buildings and indoor air quality [illegible] conducted under [illegible] administered by [illegible] important implications for a national indoor [illegible]

Department of Energy Organization Act [illegible]

The Department of Energy Organization Act [illegible] 7112) authorizes [illegible] Research [illegible] Administration [illegible] organization [illegible] stated purposes [illegible] "assuring [illegible] in the [illegible] of [illegible] advance [illegible] protection [illegible] environment [illegible] public health [illegible] Another [illegible] directed DOE to con[illegible] comprehensive [illegible] environmental [illegible] technologies [illegible]

[illegible]

[illegible] Act [illegible] of [illegible] EPA [illegible] environmental [illegible] the development of [illegible] technologies.

Atomic Energy Act

The Atomic Energy Act authorizes research important to characterizations of the problems of radon and non-ionizing radiation. The Act provided the initial charter for a comprehensive program of applied and basic radiobiological research and authorized DOE to conduct research and development related to the utilization of fissionable and radioactive materials for medical, biological and health purposes. It also provided for the protection of health during the same research and development activities. The Act also authorizes the Atomic Energy Commission "to conduct research on the biologic effects of ionizing radiation..." for "...the protection of health and the promotion of safety during research and production activities..." and for "...the preservation and enhancement of a viable environment...."

Energy Conservation and Production Act

The goal of the Energy Conservation and Production Act is the reduction of energy demand of the nation through the development of Federal and State conservation programs. The Act authorizes DOE to develop voluntary performance standards for energy efficient residential and commercial buildings, to provide technical assistance in implementing those standards, and to encourage state and local governments to incorporate those standards in building codes (42 USC 6831 et seq.). The Act also requires DOE to undertake a residential weatherization assistance program (42 USC 6863).

The Act also directs DOE to take into account the impact of energy conservation standards on "habitability" as well as the "impact on affected groups" (42 USC 6839), and to "achieve a balance of a healthful dwelling environment and maximum practicable energy conservation" in its weatherization program (42 USC 6863(b)(2)(A).

8.4 DEPARTMENT OF HEALTH AND HUMAN SERVICES (HHS)

HHS has been delegated the majority of the health-related functions of what was once the Department of Health, Education, and Welfare (HEW). It is through the role of HHS to protect the public health and to prevent disease that most programs of the Department encompass potential indoor air pollution issues. The major statutory authority defining this role is the Public Health Service Act.

Public Health Service Act (PHSA)

The Public Health Service Act provides the general mandate for the HHS to conduct research and other activities related to the causes, diagnosis, treatment, control, and prevention of disease. This statute authorizes grants, studies, dissemination of information, and an annual report on carcinogens. A comprehensive program addressing the effects of low-level ionizing radiation is specifically authorized. Regulations pursuant to this authority can be found at 21 CFR 1020, and 1030.

The PHSA directs the Secretary to identify pollution and other environmental conditions "responsible for human disease and adverse effects on humans" (42 USC 242b). The Secretary is further directed to conduct, in cooperation with EPA, the National Academy of Sciences, Department of Labor, Consumer Product Safety Commission, and Council on Environmental Quality, an ongoing study of the health costs of pollution and other environmental activities resulting from human activities "including human activity in any place in the indoor or outdoor environment, including places of employment and residences" (42 USC 242(d)(1)).

The PHSA which specifically provides for the study of the health consequences of indoor pollution, also establishes a number of health related research entities whose mandate would include specific health aspects of indoor air pollution. These mandates apply to all of the entities within the Department of Health and Human Services.

Other Legislation

The National Institute for Occupational Safety and Health obtains its primary authority for conducting indoor air quality investigations from Section 20 of the Occupational Safety and Health Act, and the Agency for Toxic Substances and Disease Registries obtains its authority for related investigations from the Comprehensive Environmental Response Compensation and Liability Act of 1980, and the Superfund Amendments and Reauthorization Act of 1986.

8.5 CONSUMER PRODUCT SAFETY COMMISSION (CPSC)

The CPSC is an independent regulatory agency that was established by the Consumer Product Safety Act (15 USC 2051) to fulfill the national goal of protecting consumers from unreasonable risks of injury. CPSC is responsible for enforcing other statutes, including the Federal Hazardous Substances Act.

Consumer Product Safety Act

The Consumer Product Safety Act (CPSA) provides CPSC with authority to control certain aspects of indoor air quality by regulating "consumer products." The CPSC can promulgate consumer product safety standards when the standard is "reasonably necessary to prevent or reduce an unreasonable risk of injury associated with such product" (15 USC 2056). Such risk or injury may include health effects associated with contaminant emissions that affect indoor air quality. In addition to setting standards, CPSC can ban a consumer product from the market.

For "substantial product hazards" CPSC has authority to (1) give public notice, (2) mail notice to manufacturers, distributors and retailers, or (3) mail notice to every person known to have been sold such a product. CPSC can also order the manufacturer to repair or replace the hazardous product, or refund the purchase price (15 USC 2064). Finally, if an "imminent hazard" exists, CPSC may sue manufacturers, distributors, or retailers (15 USC 2061).

The CPSA contains provisions applicable to the control of indoor air pollution through its provisions relating to control of consumer product sources. It vests no authority to establish indoor air quality or ventilation standards. Consumer products are defined as those for use by consumers "in and around" residences. It does not include the building itself, and the extent to which it includes building materials is unclear. In addition, product standards only apply to currently produced products, and the substantial hazard and imminent hazard provisions may be useful only if CPSC can identify the manufacturer. The CPSC is also restricted to corrective actions that cannot be taken under the terms of OSHA, the Atomic Energy Act, or the Clean Air Act.

Federal Hazardous Substances Act

The Federal Hazards Substances Act (FHSA) supplements CPSC authority under the Consumer Product Safety Act. The FHSA specifies labeling requirements for household products which are "hazardous substances", as that term is defined in the FHSA. The FHSA defines "hazardous substances" as including certain household substances or mixtures of substances which are toxic, corrosive, flammable, combustible, irritants, strong sensitizers, or substances which generate pressure through decomposition, heat, or other means. The FHSA requires labeling for hazardous substances and also bans the sale of any toy or children's article that contains or consists of a hazardous substance. Additionally, the FHSA authorizes the Commission to establish specific labeling requirements for household products containing hazardous substances if no labeling which could be required under the FHSA would adequately protect the public health and safety.

8.6 DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT (HUD)

The Department of Housing and Urban Development administers the nations housing and urban development policies which are implemented primarily through a variety of financial and technical assistance programs to state and local governments. The preeminent theme through all of its enabling statutes and which forms the basis of HUD's responsibilities in indoor air is its mandate to provide " a decent home and suitable living environment to every American family" (12 USC 1701t and 42 USC 1441). In addition, HUD is to assure that its programs provide "decent, safe, and sanitary housing" (12 USC 1701z and 42 USC 1401) or to "ensure safe and healthful working and living conditions" (12 USC 1701z-2).

In addition to this broad mandate which pervades all of HUD's authorized activities, HUD's most specific authority related to indoor air is its authority to develop construction and safety standards for manufactured housing.

National Manufactured Housing Construction and Safety Standards Act of 1974

HUD is directed by the terms of this statute (42 USC 5401) to establish standards for the construction and safety of manufactured housing. While safety aspects to be considered are primarily concerned with accident-related personal injuries, they include health and safety features related to indoor air. For example, HUD has included formaldehyde emission controls for certain wood products, and outdoor air ventilation requirements for manufactured housing using forced heat, within its regulations for manufactured housing (24 CFR 3280 and 3282).

8.7 DEPARTMENT OF LABOR (DOL)

The Department of Labor has been delegated authority to regulate health and safety conditions in places of employment. While this authority has traditionally been interpreted as applying primarily to the industrial work environment, the enabling legislation for this activity is quite broad, and covers all private sector and most public sector work environments. The primary statute of concern with respect to indoor air quality in the workplace is the Occupational Safety and Health Act.

Occupational Safety and Health Act (OSHAct)

The Occupational Safety and Health Administration (OSHA) was created in 1970 under OSHAct (16 USC 651 et seq.), wherein Congress declared it a national policy "to assure as far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources ..." by, among other things, directing the Secretary of Labor to develop and enforce occupational safety and health standards.

The OSHact requires the Secretary of Labor, in the case of standards dealing with toxic substances, to set "the standard which most adequately assures to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life."

In addition to safety and health, the standards must take into account issues of feasibility. OSHA occupational indoor air standards are enforced by inspecting workplaces and where warranted by prescribing abatement, and proposing civil monetary penalties.

The National Institute for Occupational Safety and Health (NIOSH), which resides in the Department of Health and Human Services, was created by Congress in the OSHAct to develop and establish recommended occupational safety and health standards and to perform other functions (29 USC 671).

8.8 SUMMARY AND IMPLICATIONS

The preceding discussion illustrates a number of significant points that are pertinent to assessing the adequacy of existing laws to protect indoor air quality.

First, many Federal agencies have the explicit legal authority to regulate certain products and/or activities that affect indoor air quality, or to regulate the quality of the air in specific indoor environments. Existing authority ranges from the ability to ban or restrict the use of pesticides and consumer products, to setting and enforcing indoor air quality standards in occupational settings. However, these authorities are fragmented, are limited to specific products or environments, and some address indoor air concerns secondarily or only implicitly.

Second, most legal authority related specifically to building systems affecting indoor air quality is limited in scope, allowing only research activities and provision of public information and technical guidance. Most of this authority rests with the Department of Energy and is directed to energy conservation, with indoor air quality as a secondary concern.

Finally, there is currently no Federal law that explicitly establishes a goal of establishing acceptable indoor air quality in non-occupational environments which protect the public health and welfare. In addition, while SARA Title IV vests in EPA the responsibility to conduct research, coordinate, and disseminate information, it does so in the context of research, and does not delegate authority for controlling indoor air pollution. Thus, there is currently no Federal agency with comprehensive authority to develop a coherent, national indoor air pollution control program for residential, most educational, and other non-occupational indoor air environments.

CHAPTER 9 - INDOOR AIR POLLUTION CONTROL PROGRAMS

Government and private entities at the local, state, national, and international levels have developed programs to execute indoor air quality control policies and strategies. This chapter summarizes indoor air quality efforts of Federal, state, and local agencies; private sector organizations; foreign governments; and international organizations.

9.1 FEDERAL PROGRAMS

The Federal government participates in the study and control of indoor air quality through the activities of a number of its agencies and departments. The agencies that comprise the Interagency Committee on Indoor Air Quality (CIAQ) have implemented indoor air quality control programs based on the legislative authority discussed in Chapter 8. This chapter summarizes the indoor air quality assessment and control activities of Federal agencies, especially the CIAQ co-chairs and the Bonneville Power Administration. Volume I of this report contains a more complete description of current and planned indoor air quality control activities at the Federal level.

Environmental Protection Agency

The Environmental Protection Agency's (EPA's) indoor air quality control efforts attempt to (1) characterize indoor air problems; (2) identify, assess, and implement strategies to mitigate indoor air hazards; and (3) disseminate information about indoor air quality control. In accordance with these aims, EPA uses mandatory standards and procedures, voluntary guidelines, research activities, and dissemination of public information and technical assistance to implement its indoor air program.

EPA efforts to understand and control indoor air hazards are presented in Exhibit 9-1. EPA has developed a limited number of regulatory controls on indoor air hazards. Most of EPA's current mandatory standards and procedures arise from the pesticide and asbestos programs of the Office of Pesticides and Toxic Substances. EPA actively studies many facets of indoor air concerns, ranging from characterizing typical concentrations and exposures to evaluating control strategies. EPA also actively disseminates information on indoor air quality concerns through booklets, fact sheets, telephone hotlines, product labelling, and manuals and workshops for professionals.

Consumer Product Safety Commission

The Consumer Product Safety Commission (CPSC) addresses indoor air quality concerns by developing voluntary guidelines

[illegible]

[illegible] Indoor Air Quality [illegible] Activities

[illegible]

Regulatory Standards [illegible]

MCLs for Radon and VOCs	Drinking water standards incorporating indoor air exposures
Asbestos Ban and Phase Down Rule	Restriction on the use of asbestos-containing materials in buildings
Asbestos Worker Protection Rule	Procedures and standards for asbestos removal work
Asbestos Materials in Schools Rule	Support for identification and removal of problem asbestos in schools
Ban on Sales of Chlordane and Heptachlor	Sales ban pending demonstration of safe application methods
Restrictions on Lindane Use	Ban on use of indoor fumigating devices
Restrictions on Pentachlorophenol and Creosote	Ban on treating wood used indoors with these chemicals
Proposed Suspension of Indoor Use of Certain Anti-Microbials	Proposed ban on use of certain anti-microbials in indoor environments

Voluntary Guidelines

Model Building Code	Appropriate design features to control radon infiltration

Research

Measurement and Estimation of Exposures and Concentrations	More than 30 projects investigating sources, monitoring, and exposures
Health Effects	Nine projects involving ETS, radon, VOC mixtures, and combustion gases
Risk and Hazard Assessment	Five projects involving ETS, para-dichlorobenzene, and solvents
Diagnosis, Assessment, and Mitigation Protocols	Five projects investigating sick building syndrome, air exchange, and radon control measures
Controls Assessment	Three projects including radon/chlordane control, air cleaner evaluation, and testing radon control methods

[illegible]

Publications for [illegible] Education	Fact Sheets, indoor air booklet, and radon "citizen's guide" and mitigation pamphlets
[illegible]	Toll-free numbers for questions about asbestos and pesticides
Product Label Requirements	Inert ingredients in pesticides, support of voluntary consumer awareness programs by pesticide manufacturers
Technical Support Manuals and [illegible]	Course for public health specialists, information on radon provided to AMA and Conference of State Legislators

Activity	[illegible]
Mandatory Standards [illegible]	
Carbon Tetrachloride [illegible]	[illegible]
Asbestos Use Ban	[illegible] compounds
Vinyl Chloride Ban	Ban on use of [illegible]
Voluntary Guidelines	
Combustion Device Performance Guidelines	Recommended limits for emissions from kerosene heaters and unvented gas space heaters
Formaldehyde Emission Guidelines for Wood Products	[illegible] wood products
Research	
Measurement and Estimation of Exposures and Concentrations	[illegible]
Health Effects	[illegible]
Risk and Hazard Assessment	[illegible]
Controls Assessment	[illegible] stoves and air filter evaluations
Information Dissemination	
Publications for Public Education	Indoor air guidance including asbestos in homes
Product Label Requirements	Including warnings on asbestos [illegible]

[illegible] programs designed to [illegible] indoor air [illegible] quality. These [illegible] implement these [illegible] primarily through voluntary guidelines and research.

Department of Energy

In support of its policies to eliminate potential hazards to the public from radioactivity at past and current atomic energy program facilities, and to develop and provide information needed to maintain healthful indoor environments with the continuing use of energy conservation measures in buildings, the Department of Energy (DOE) undertakes indoor air quality problem characterization and mitigation research and disseminates public information and technical assistance.

Specific DOE research and information dissemination activities directed at improving knowledge of indoor air quality concerns are described in Exhibit 9-1. DOE primarily directs its research efforts to investigating the hazards of indoor radon and the effects of building weatherization.

Bonneville Power Administration

Within DOE, the Bonneville Power Administration (BPA) has undertaken a variety of activities to control indoor air quality in response to the potential indoor air health hazards created by its energy conservation programs. Exhibit 9-1 summarizes BPA's standards, guidelines, research activities, and information dissemination efforts related to indoor air quality. As a consequence of its development of the Administration's energy conservation programs, BPA's indoor air effort focuses on residential air quality as it is affected by weatherization efforts.

Department of Health and Human Services

The Department of Health and Human Services (HHS) participates in indoor air quality control through research and information dissemination activities. Exhibit 9-1 presents a summary of these HHS activities. The Department's research activities center primarily on indoor pollutant health effects. Through the National Institute for Occupational Safety and Health, HHS investigates complaints for indoor air quality problems. HHS also disseminates information and technical assistance on indoor air concerns to state and local governments and the public.

Exhibit 9-3

DOE Indoor Air Quality Control Activities

Activity	Description
Research	
Measurement and Estimation of Exposures and Concentrations	Nineteen projects focusing on radon, modeling, and energy conservation
Health Effects	Four projects concerning radon
Risk and Hazard Assessment	Two projects concerning radon
Diagnosis, Assessment, and Mitigation Protocols	Five projects investigating infiltration and ventilation
Controls Assessment	Review and development of current technology
Information Dissemination	
Publications for Public Education	Handbooks on combustion sources, indoor radon, and building systems
Technical Support Manuals and Services	Database of indoor pollutant concentrations, handbooks on indoor air issues

Exhibit 9-4
BPA Indoor Air Quality Control Activities

Activity	Description
Mandatory Standards and Procedures	
Emission Limit for Formaldehyde in Wood Products	Required use of low-formaldehyde materials in residential buildings
Voluntary Guidelines	
Action Limit for Radon	Mitigation assistance for weatherized homes with radon concentrations greater than 5 pCi/L
Research	
Measurement and Estimation of Exposures and Concentrations	Seven projects investigating monitoring and weatherization effects
Controls Assessment	Six projects investigating radon control methods, local exhaust, heat exchangers
Information Dissemination	
Publications for Public Education	Pamphlets on ventilation and air quality, issue "backgrounders"
Technical Support Manuals and Services	Manuals on radon monitoring, installing mitigation devices, auditing and operating HVAC systems; distributing radon detectors

Exhibit 9-5
HHS Indoor Air Quality Control Activities

Activity	Description
Research	
Measurement and Estimation of Exposures and Concentrations	Six projects including surveys of attitudes and practices, radon screening, post-remedy tests, and studies of ETS and fibrous particulates
Support for Indoor Air Quality Investigation	Ongoing research studying the ventilation, clinical, and psychosocial parameters of indoor air quality investigations
Health Effects	More than 30 projects studying Legionella, allergens, and chronic lung disease
Information Dissemination	
Publications for Public Education	Report on passive exposure to tobacco smoke
Technical Support Manuals and Services	Services for state health departments, epidemiological information on radon, campaign to encourage smoking restriction legislation, and a manual of analytical methods for air sampling and analysis
Assessment Services	NIOSH [a] Health Hazard Evaluations

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[a] NIOSH is the National Institute for Occupational Safety and Health, part of HHS.

Other Federal Agencies

A number of other Federal agencies play smaller, but active, roles in controlling indoor air quality. The indoor air-related activities of the Departments of Defense (DOD), Housing and Urban Development (HUD), State (DOS), and Transportation (DOT); the Federal Trade Commission (FTC); the General Services Administration (GSA); the National Aeronautics and Space Administration (NASA); the National Institute of Standards and Technology (NIST); the National Institute of Building Sciences (NIBS); the National Science Foundation (NSF); the Occupational Safety and Health Administration (OSHA); the Tennessee Valley Authority (TVA); and the Veterans' Administration (VA) are presented in Exhibit 9-6. These agencies promulgate mandatory standards and procedures, conduct research, and disseminate information to the public and concerned professionals.

Summary of Federal Agency Indoor Air Quality Control Programs

In this section, we have described the indoor air quality control programs of federal agencies in terms of mandatory standards and procedures, voluntary guidelines, research activities, and public information and technical assistance. Exhibit 9-7 summarizes these federal activities according to the directness of their application to indoor air quality control.

Indoor Air Quality Control Activities

Federal efforts to control indoor air quality can be classified as (1) air quality standards; (2) restrictions on potential indoor emissions of pollutants through restricting the manufacture, sale, and/or use of potential sources of indoor air pollution; and (3) assessment and mitigation procedures.

- Only OSHA has implemented comprehensive air quality standards for the indoor environment.

- EPA, CPSC, BPA, DOD, HUD, DOT, GSA, and VA have developed efforts to control indoor air quality by restricting pollutant emissions from specific products.

- EPA, DOD, GSA, and NASA have implemented assessment and mitigation procedures to identify and correct indoor air problems. These assessment and mitigation programs apply to small subsets of the building population of the U.S.; for example, EPA's asbestos removal program applies only to schools and GSA's proposed assessment procedure only to buildings under GSA control.

Exhibit 9-6
Other Federal Agencies' Indoor Air Quality Control Activities

Activity and Agency	Description
Mandatory Standards and Procedures	
DOD	Restrictions on smoking in Air Force structures, assessment and mitigation plans for Air Force structures, chlordane assessments
DOT	Restrictions on smoking on commercial airline flights, standards for pollutants and ventilation in airline cabins
HUD	Formaldehyde emission limits for materials in manufactured housing
GSA	Smoking restrictions in GSA buildings, building assessment procedures
NASA	Adoption of OSHA values for NASA facilities, Legionella control, and HVAC maintenance
OSHA	Concentration and exposure limits for the industrial workplace
VA	Prohibition on purchase or use of asbestos
Research	
Exposure and Concentration Estimation and Measurement	
DOT	Evaluate effects of smoking on airliner cabin air quality
NASA	Test material offgassing
NIST	IAQ concentration model
NSF	Awards scholarships, fellowships, grants, loans, and contracts for basic research
TVA	Radon, NO_2 dynamics, energy conservation
Health Effects	
TVA	NO_2 effects on school children
Risk and Hazard Assessment	
DOS	Indoor air hazards in DOS buildings
Diagnosis, Assessment, and Mitigation Protocols	
HUD	Housing site assessment
GSA	Diagnostic technique validation
NIST	Air movement test method
Controls Assessment	
NASA	Pollutant gas removal by houseplants
NIST	Test method for removal equipment in HVAC
TVA	Assessments of radon mitigation methods, heat exchangers
Information Dissemination	
Publications for the General Public	
HUD	Guide to new home investigations
TVA	IAQ materials, speakers for public meetings
Telephone Hotlines	
TVA	Citizen Action Line for citizen inquiries
Product Label Requirements	
FTC	Guidelines for advertising of products with indoor air impacts
HUD	Certification of wood products used in manufactured housing
Technical Support Manuals and Services	
NASA	Chapter on indoor air concerns in "Space Biology and Medicine"
NIST	Radon measurement standard and calibration
NIBS	Building performance criteria and technical standards for incorporation into building codes or other regulations
Workshops and Training Courses	
NIST	Modeling workshops

Exhibit 9-7
Summary of Federal Indoor Air Quality Control Activities

Point of Impact	Agency/Activity	Comments
Direct Control of Indoor Concentrations and/or Exposures	• OSHA Air Standards	Limited to industrial environments
	• BPA Radon Action Level	Limited to residences in BPA's weatherization program
	• NASA Air Standards	Adopted OSHA standards
Control of Emissions by Restricting Activities or Product Composition	• EPA Drinking Water MCLs for Radon and VOCs	Indoor air exposures considered in determining drinking water levels
	• EPA Pesticide Restrictions	Restricts use and sales of pesticides which may cause indoor air pollution
	• CPSC Consumer Product Bans	Bans on use of some potential indoor pollutants in consumer products
	• Smoking Restrictions Imposed by DOD, DOT, and GSA	Restricts smoking in specified indoor environments
	• VA Restrictions on Asbestos Use	Restricts use of asbestos in VA buildings
Control Through Assessment and Mitigation Procedures	• EPA Asbestos Rules	Provides for the assessment and mitigation of asbestos hazards in schools
	• GSA Building Assessments	Investigates GSA-controlled buildings for indoor air problems
	• NIOSH Building Assessments	Responds to air-quality health complaints
	• DOD/USAF Chlordane Assessments	Investigates USAF facilities for chlordane problems
	• NASA HVAC System Maintenance	Assesses and corrects HVAC operation to optimize indoor air quality
Efforts to Increase Knowledge of Indoor Air Quality Problems and Controls	• Research efforts by EPA, CPSC, DOE, HHS, BPA, DOT, NASA, NIST, NSF, TVA, DOS, HUD, and GSA	
	• Information Dissemination by EPA, CPSC, DOE, HHS, BPA, HUD, TVA, FTC, NASA, NIST, and NIBS	

Agencies have implemented these indoor air quality activities through mandatory standards and voluntary guidelines.

- EPA, CPSC, BPA, DOD, DOT, HUD, GSA, NASA, OSHA, and VA control indoor air concerns with mandatory standards and procedures.

- CPSC, EPA, and BPA have used voluntary guidelines to control indoor air concerns.

  - CPSC has assisted in the development of voluntary standards for emissions from wood products and some combustion devices to control the quality of the indoor atmosphere.
  - EPA is developing a voluntary guideline approach to radon mitigation through its work on a model building code and its use of a radon action level for recommending mitigation.
  - The BPA weatherization program's radon monitoring and mitigation activities are available to homeowners on a voluntary basis.

Federal Efforts to Increase Knowledge of Indoor Air Concerns

Federal research of indoor air quality issues is directed toward improving our ability to (1) estimate and measure concentrations and exposures; (2) relate indoor air quality to health effects; (3) assess risk and hazard; (4) develop diagnosis, assessment, and mitigation protocols; and (5) assess control techniques. Federal agencies have distributed their efforts among these areas of research according to functional boundaries;

- EPA has a lead role in most areas of research,

- DOE leads efforts to characterize and identify the hazards of radon,

- HHS efforts lead investigations of the health effects of indoor air pollution.

Federal agencies provide public information and technical assistance to lower levels of government and the public through (1) publications for the general public, (2) telephone hotlines, (3) labeling requirements, (4) technical manuals or procedures, and (5) workshops and training courses.

- Publications for public and specialized technical consumption are the most commonly used communication techniques.

- Product labeling requirements have been implemented by agencies with the appropriate statutory authority.

9.2 STATE AND LOCAL INDOOR AIR QUALITY PROGRAMS

Much of the governmental effort to ensure clean indoor air occurs at the State and local level. Many State and local governments address indoor air concerns through restrictions on smoking in public spaces, ventilation requirements in building codes, asbestos inspection and removal programs, pollutant concentration and emission standards, problem building evaluations, and research and public information dissemination activities. California has implemented the most comprehensive indoor air quality program (Wesolowski, et al., 1984). This section describes some notable State and local efforts to control the quality of the indoor atmosphere through these types of initiatives.

Smoking Restrictions

Forty-two states and at least 194 localities regulate smoking in public places to some extent (TFYA, 1988). The extent of restrictions imposed by these regulations varies considerably, but all aim to protect the right of occupants of public spaces to a smoke-free indoor atmosphere. Exhibit 9-8 illustrates the range of public areas affected by some State and local smoking restrictions.

- Most State smoking restrictions limit smoking in buses, health care facilities, schools, elevators, government buildings, gymnasia/arenas, restaurants, retail and grocery stores, and at public meetings (TFYA, 1987).
- Half of the State regulations control smoking in the public sector workplace (TFYA, 1988).
- Less than half of the State smoking limitations apply to hotels, libraries, museums, public places, restrooms, and theaters (TFYA, 1987).

Building Operation Requirements

A number of State and local governments incorporate indoor air quality considerations into building codes. Exhibit 9-9 presents examples of this type of regulation. These examples do not attempt to provide a complete list of such regulations, but merely illustrate the variety of the regulatory mechanisms to address indoor air concerns that may be found in contemporary building codes. Refer to Standards, Regulations, and Other Technical Criteria Related to Indoor Air Quality (NIBS, 1986) for more detailed information on these requirements.

Exhibit 9-8
State and Local Smoking Restrictions

State or Locality	Restrictions
Minnesota	• Affected areas include public buildings, public meetings, health care and day care facilities
Utah	• Affected areas include public buildings, places of business, offices, eating places • Specifies size and posting requirements for segregated smoking areas
Connecticut	• Affected areas include elevators, health care institutions, public schools, retail food stores, and part of any restaurant with 25 or more seats, and during government meetings
Los Angeles	• Prohibits smoking in elevators, nurse rooms, restrooms, theaters, and public business places • Employers are required to provide nonsmoking areas for employees
San Diego	• Prohibits smoking in retail stores, retail service establishments, food markets, theaters, auditoriums, places of public assembly, meeting rooms, restrooms, elevators, and museums
Denver	• Regulates smoking only in retail food establishments

Sources: NIBS, 1986; Oatman, 1988.

Exhibit 9-9

State and Local Building Operation Requirements

State or Locality	Regulations Relevant to Indoor Air Quality Control
California	• The tightest of new residences must achieve at least 0.7 air changes per hour • ASHRAE Standard 62 ventilation requirements adopted • Workplaces must be monitored to ensure that ASHRAE Standard 62-1981 ventilation rates are met in building operation
New York (State)	• Energy Conservation Construction Code adopts ASHRAE Standards 62-73 and 90-75
South Dakota	• Medical Facilities Building Code specifies ventilation system design and operation requirements to supply acceptable indoor air quality
New Jersey	• Public Employee Occupational Safety and Health Act requires ASHRAE Standard 62-1981 ventilation rates in State occupied buildings
Massachusetts	• Ban on the use of urea-formaldehyde foam insulation in building construction
Los Angeles	• Adopted 1982 Edition of the Uniform Building Code, incorporating minimum ventilation limits for places of assembly, garages, and residences

Sources: NIBS, 1986; COSHSB, 1986; Domarcki, 1984; NJDH, no date; MSCIAP, 1987.

A number of States have developed procedures for evaluating buildings in response to health complaints related to indoor air quality. Assessment procedures used in West Virginia and New Jersey provide examples of State developed problem building evaluation procedures. West Virginia has developed a set of general principles to guide the resolution of indoor air complaints: complaint screening, interview/investigation, testing, and data interpretation (NIBS, 1986). West Virginia measures carbon monoxide and carbon dioxide concentrations as indicators of building air quality. New Jersey emphasizes implementing control options rather than monitoring air quality in its standardized response to indoor air quality-related health complaints by State employees (Freund, 1987).

Asbestos Inspection and Removal

Exhibit 9-10 summarizes state asbestos programs. Under the Asbestos Hazard Emergency Response Act states have implemented programs for building inspections, building management plans, accreditation programs for asbestos professionals, abatement standards, and enforcement standards. Refer to the survey results by Neilander and Sacarto (1988) for more detailed information.

New Jersey asbestos abatement standards provide an example of requirements which go beyond federal standards; New Jersey's Uniform Construction Subcode on Asbestos Hazard Abatement requires that only personnel with approved training may undertake removal actions and specifies that major actions require "substantial protection and precaution" and must not exceed airborne asbestos limits during removal activities (NIBS, 1986).

Radon Programs

States have undertaken a variety of activities to study and mitigate radon problems in buildings. State efforts may be classified into four categories: (1) information programs, (2) formative programs, (3) developing programs, and (4) operational programs (EPA, 1987). Exhibit 9-11 presents a summary of the status of state radon programs. Refer to EPA's Summary of State Radon Programs (EPA, 1987) for a more detailed discussion of State radon programs.

Pollutant Concentration and Emission Standards

Few states have addressed indoor air pollution concerns by promulgating limits on indoor concentrations or emissions of various contaminants. Some states have adopted standards for formaldehyde and at least two states have incorporated OSHA standards for non-industry workplaces. Exhibit 9-12 presents examples of these standards. Refer to Standards, Regulations,

Exhibit 9-10
Summary of State Asbestos Control Programs

Building Inspections

Schools	• Eleven states require inspections by statute • Three states conduct inspections as a matter of policy
State-Owned Buildings	• Eleven states require inspections by statute • Nine states conduct inspections as a matter of policy
Other Buildings	• Four states require inspections of other types (e.g., municipal) of buildings

Building Management Plans

Schools	• Eight states require management plans by statute or regulation
State-Owned Buildings	• Nine states require management plans by statute or regulation • Eight states develop and implement management plans as a matter of policy
Other Buildings	• Four states require management plans in other buildings

Accreditation

- 39 States have some type of accreditation program
- Ten states have statutes and are currently promulgating regulations
- Four states license contractors with demonstrated completion of an EPA-approved asbestos training course

Abatement Standards

- 38 States have adopted NESHAP-type regulations and have enforcement authority from EPA
- 23 States have adopted OSHA-type standards relating to asbestos

Enforcement Standards

- Most states can conduct on-site inspections and levy civil fines for violations

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Source: Neilander and Sacarto, 1988.

Exhibit 9-11
Summary of State Radon Programs

Program Type	Definition	States
Information	No active program, disseminates information	Arkansas, Hawaii, Louisiana, Mississippi, Nevada, South Dakota, Texas
Formative	Preliminary surveys	Alaska, Arizona, California, Delaware, Georgia, Idaho, Iowa, Massachusetts, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, South Carolina, Utah, Vermont, Washington, West Virginia
Developing	Extensive surveys	Alabama, Colorado, Connecticut, Illinois, Indiana, Kansas, Kentucky, Maryland, Michigan, Rhode Island, Tennessee, Virginia, Wisconsin, Wyoming
Operational	Comprehensive surveys demonstrating problems	Florida, Maine, New Jersey, New York, Pennsylvania

Source: EPA, 1987.

Exhibit 9-12
State Pollutant Concentration and Emission Standards

State	Standard
Minnesota	• Formaldehyde emission limits for all building materials in all types of construction • Maximum ambient concentrations of combustion products in arenas where combustion devices are used
Wisconsin	• Formaldehyde emission limits for mobile homes
Wyoming	• OSHA threshold concentrations incorporated into standards applicable to workplaces, warehouses, commercial buildings, offices, and hospitals
New York	• OSHA standards and regulations adopted for places of State employment

Sources: NIBS, 1986; Oatman, 1988; WDHSS, no date.

and Other Technical Criteria Related to Indoor Air Quality (NIBS, 1986) for more detailed information about these standards.

Information Dissemination and Research Programs

State and local public information programs communicate indoor air quality concerns and control options to the public and other governments within their jurisdiction by way of informational brochures, telephone response to inquiries, and training programs. States are also active in indoor air research to a limited extent. Examples of these types of State and local activity are presented in Exhibit 9-13.

9.3 PRIVATE SECTOR INITIATIVES

A diverse group of private organizations actively participates in efforts to understand and control indoor air pollution. Standard setting organizations, trade associations, public interest groups, and private companies offering services or products related to indoor air quality control all contribute their expertise to control the quality of the indoor atmosphere. The following discussion is not a complete accounting of all private groups active in indoor air quality control, but illustrates the efforts of groups most actively involved in indoor air quality issues and the range of contributions available from the private sector. Exhibit 9-14 presents summary information about the indoor air quality control activities of standard setting organizations, Exhibit 9-15 illustrates indoor air-related activities of some professional trade associations, and Exhibit 9-16 presents indoor air-related activities of public interest organizations. EPA is currently investigating the capabilities of the private sector to provide diagnostic and mitigation services.

9.4 INTERNATIONAL AND FOREIGN PROGRAMS

Foreign and international efforts to study and address indoor air concerns parallel activities undertaken in this country. The governments of Canada and several Western European countries, and the World Health Organization European Regional Office are the leading contributors to understanding and controlling indoor air quality concerns outside the United States. In this section we briefly present some of their important indoor air quality control efforts.

World Health Organization, Regional Office for Europe

The World Health Organization (WHO) has, during the past ten years, taken the lead in indoor air quality issues in Europe. WHO has implemented research and communication programs related to indoor air quality and developed guidelines for pollutant concentrations in the indoor and outdoor atmosphere.

Exhibit 9-13

State and Local Information Dissemination and Research Programs

State or Locality	Program Description
California	• "Consumer Cleanup Kit" to help reduce residential exposures • Training program for local governments • Permanent research unit to integrate indoor air quality and human monitoring studies -- actively investigates a variety of indoor air quality concerns
West Virginia	• Formaldehyde hazards pamphlet
New York	• Formaldehyde hazards pamphlet
Pennsylvania	• "How-to" publication of general techniques for reducing radon concentrations
Maryland	• Booklet explaining indoor air pollution and mitigation for use by local school districts
Massachusetts	• Special commission to study indoor air issues and control options
St. Louis	• Pamphlet on hazards of dusts and fumes from lead-based paints

Sources: NIBS, 1986; MSDE, 1987; Wesolowski et al., 1984; MSCIA, 1987.

Exhibit 9-14
Standard Setting Organization Indoor Air Activities

Organization	Activities
American Conference of Governmental Industrial Hygienists (ACGIH)	• Develops indoor air quality guidelines for industrial exposures • Convenes a committee on bioaerosols • Publishes a manual on air sampling instrumentation
American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)	• Develops "Ventilation for Acceptable Indoor Air Quality," Standard 62-1981 • Develops a thermal comfort standard • Develops an energy conservation standard • Publishes technical information • Provides continuing education for its membership • Supports research
American Society of Testing and Materials (ASTM)	• Convenes a technical committee on sampling and analysis of atmospheres • Develops test methods for atmospheric analysis • Publishes technical books • Sponsored 1987 conference, "Design and Protocol for Monitoring IAQ"
Building Officials and Code Administrators, Inc. (BOCA)	• Develops National Building and Mechanical Code -- specifies ventilation design and operation requirements which affect indoor air quality
Council of American Building Officials (CABO)	• Develops One and Two Family Dwelling Code -- specifies ventilation requirements which affect indoor air quality
National Environmental Balancing Bureau (NEBB)	• Develops procedural standards for testing, adjusting, and balancing environmental systems • Produces a directory of firms certified to perform environmental testing, adjusting, and balancing
Southern Building Code Congress International, Inc. (SBCCI)	• Develops building, fire, and mechanical codes -- specifying procedures which affect indoor air quality
Underwriters' Laboratory (UL)	• Conducts product and equipment testing for public safety -- including ranges, ovens, ESP, manufactured fireplaces, HEPA filter units

Sources: NIBS, 1986; Morey et al., 1986; ASHRAE, no date; ASTM, 1988; NEBB, no date; Przybylski, 1988.

Exhibit 9-15
Professional and Trade Association Indoor Air Activities

Organization	Activities
Air Conditioning Contractors of America (ACCA)	• Publishes technical manuals on air conditioning design, installation, and maintenance
Air-Conditioning and Refrigeration Institute (ARI)	• Rates performance of air-to-air heat exchangers, filter equipment assemblies and refrigeration systems • Convenes a standing committee on indoor air quality
Air Pollution Control Association (APCA)	• Convenes indoor air sessions at APCA annual meetings • Convenes specialty conferences on indoor air-related issues
American Gas Association (AGA)	• Develops standards addressing gas leaks and combustion product emissions
American Industrial Hygienists Association (AIHA)	• Convenes an Indoor Environmental Quality committee • Publishes industrial hygiene guidance documents • Developing guidance on indoor air quality
American Insurance Assc.	• Monitors environmental issues for liability implications to member insurers
American Plywood Association (APA)	• Recommends practices for handling preservative, treated wood products, using chlorpyrifos, and applying subfloor vapor barriers
Architects Institute of America (AIA)	• Sponsored and published proceedings of a national symposium on indoor air pollution and the architect's response
Electric Power Research Institute (EPRI)	• Sponsors research of indoor air quality as it relates to energy consumption and HVAC systems
Gas Research Institute (GRI)	• Sponsors research of indoor air quality concerns of the natural gas industry • Licenses manufacturers of burner inserts for nitrogen oxide emission reduction
Hardwood Plywood Manufacturers Association (HPMA)	• Developed a voluntary standard for formaldehyde emissions from wood products
Home Ventilation Institute (HVI)	• Active in ASHRAE Project Committee on Standard 62-1981 • Develops standards for heat recovery ventilators
National Association of Home Builders (NAHB)	• Supports research of building components and operating parameters which affect indoor air quality • Conducts an annual survey of construction materials • Provides technical assistance to home builders
National Plywood Association (NPA)	• Developed a voluntary standard for formaldehyde emissions from particleboard
Public Health Foundation (PHF)	• Developing a directory of state indoor air contacts and surveying state indoor air quality programs
Service Employees International Union	• Surveys and investigates indoor air problems of public service workers, educates members, and promotes legislative and regulatory solutions
Sheet Metal and Air Conditioning National Association (SMACNA)	• Provides membership with education through manuals and a home study course
Tobacco Institute	• Conducts programs to preserve the rights of smokers and member companies against unwarranted government restraint

Source: NIBS, 1986; ACCA, 1987; APCA, 1988; GEOMET, 1987; Tinkleman, 1988; GRI, 1986 and 1985; HPMA, 1987; Barron, 1985; Bevirt, 1988; personal communications.

Exhibit 9-16
Public Interest Organization Indoor Air Activities

Organization	Activities
American Lung Association (ALA)	• Issued a position paper on indoor air pollution • Distributes information sheets on indoor air pollution hazards
Americans for Nonsmokers' Rights (ANR)	• Develops and distributes model clean indoor air legislation
American Public Health Association (APHA)	• Conducting study on validity and prevalence of multiple chemical sensitivity
Consumer Federation of America (CFA)	• Testifies before Congress about indoor air concerns • Publishes quarterly newsletter, Indoor Air News" • Convened EPA-cosponsored IAQ conferences, 1986-1988
Consumers Union (CU)	• Publishes product testing results in Consumer Reports. Recently tested air cleaners, unvented kerosene heaters, air-to-air heat exchangers, and radon detectors
National Council for Clean Indoor Air (NCCIA)	• Convened EPA-cosponsored policy forum on indoor air quality issues • Testifies before Congress about indoor air concerns
National Institute for Building Sciences (NIBS)	• Improves building regulatory environment and facilitates the introduction of building technology • Prepared report on building standards related to indoor air • Provides guidance/information, conducts workshops/conferences on building IAQ issues
Tobacco-Free Young America Project (TFYA)	• Acquires and disseminates information on state and local smoking regulations

Sources: NIBS, 1986; ALA, 1982; ANR, no date; Weiss, 1988; GEOMET, 1987; Helm, 1988; TFYA, 1987.

In 1978, WHO formed a working group, with members from ten European countries, on assessing and monitoring exposure to indoor air pollutants. This group has co-sponsored several international conferences on indoor air quality and climate. These conferences address such topics as identifying indoor sources, monitoring concentrations of pollutants in indoor microenvironments, and assessing indoor air pollution health effects and control strategies.

WHO has issued air quality guidelines for 12 organic and 16 inorganic air pollutants (WHO, 1987). WHO carefully considered the relative importance of indoor air quality in developing these guidelines, which do not differentiate between indoor and outdoor exposure. (These guidelines are discussed more completely in Chapter 7.) WHO presents these guidelines as tools for use by decision makers in determining appropriate courses of action for the control of air pollutants; the guidelines should not be considered standards, although in the proper context they can assist in the development of standards or other control strategies. A number of European countries are currently considering the WHO guidelines as they develop indoor air quality control programs (Stolwijk, 1988).

An important ongoing WHO research program is the Human Exposure Assessment Location (HEAL) project. Similar to EPA's TEAM studies, HEAL involves field investigations to measure comparative pollutant exposures and body burdens in different countries.

Canada

Under the auspices of the Ministry of Health and Welfare, Canada formed a Federal-Provincial working group on indoor air quality in 1981 that is modeled after the WHO working group. The Canadian group has issued guidelines on maximum acceptable indoor air concentrations for nine substances and recommendations for controlling exposure to nine other substances. The scope of the guidelines is restricted to "domestic premises" and they are designed to protect the general public, assuming exposure for 24 hours per day. The use of these guidelines as regulatory limits is left to the provinces, some of which are attempting to implement them as mandatory standards at the present time (Walkinshaw, 1988).

In other indoor air quality control efforts, Canada controls formaldehyde exposures from urea-formaldehyde foam insulation (UFFI) through a product ban and specifies ventilation requirements in a national building code. Canada banned the use of UFFI in 1980 and implemented an assistance program for its removal from residences (Shurb, 1986). Canada's national building code (1985 edition) requires a ventilation rate of at least 0.5 air changes per hour with either manual or automatic controls (Kerwin, 1986).

United Kingdom

The United Kingdom (U.K.) has addressed a number of indoor air quality concerns through direct regulation and voluntary standards. Programs are in place to control indoor exposures to asbestos, formaldehyde, and combustion products (Llewellyn and Warren, 1986).

The U.K. asbestos control program consists of two major initiatives. The first part of the program involves disseminating information on the hazards of asbestos through two publications and a monitoring and removal program to control asbestos emissions at the source. The second major initiative bans asbestos spraying and all uses of some types of asbestos.

Formaldehyde control with respect to UFFI in the U.K. relies on self-enforcement by industry of foam insulation formulation and installation codes. The codes specify proper formulation and installation procedures; manufacturers sell supplies only to members of trade associations that have adopted these standards.

Combustion products, especially CO, have received attention in the building code of the U.K. The national building regulations attempt to control combustion pollutants through ventilation requirements to ensure adequate supply air.

Scandinavian Countries

Scandinavian countries conduct extensive research on building-related indoor air quality problems and several countries have specific ventilation requirements to control indoor air quality. A Nordic Committee on Building Codes has adopted a minimum whole-house ventilation rate of 0.5 air changes per hour. Similar requirements have been adopted in the national building codes of Denmark, Finland, Norway, and Sweden. Norway and Finland have adopted the 0.5 air changes per hour minimum. Norway supplements this requirement with prescribed duct sizes for natural ventilation or air flow rates required for the mechanical ventilation of specific indoor environments. Finland's national building code specifies ventilation rates for various indoor locations and defines goal concentrations of CO_2 and other pollutants in the indoor atmosphere. Sweden's mandatory whole house ventilation rate is 0.35 liters per second per square meter of dwelling area. Danish building regulations require ventilation of at least 0.4 air changes per hour for general living areas and 0.7 air changes per hour for kitchens and bathrooms. Other chapters of this code specify rates for mechanical ventilation and restrictions on humidifying and cooling inlet air.

Formaldehyde contamination is also a concern in Scandinavian countries (Stolwijk, 1988); accordingly, Danish building regulations limit the use of formaldehyde-containing products in building construction.

9.5 SUMMARY AND IMPLICATIONS

Some programs related to the control of indoor air quality are available in the United States and in other countries. Significant potential exists for cooperative coordinated indoor air control programs of Federal, State, and local governments, and in the private sector. Currently, coordination is achieved through professional associations, voluntary standards organizations, and the Federal Interagency Committee on Indoor Air Quality. Current programs at all levels of government and the private sector are generally fragmented and underfunded.

Programs of various agencies of the U.S. government relate to individual agency mandates which were discussed in Chapter 8. Some state and local governments conduct programs, most of which involve restrictions on smoking, or specific provisions in building codes. Some states have taken specific actions on individual contaminants. Many foreign governments conduct indoor air quality activities. International coordination is fostered through such entities as the World Health Organization.

REFERENCES

Air Conditioning Contractors of America (ACCA). 1987. 1987 ACCA Catalog. Washington, D.C.

Air Pollution Control Association (APCA). 1988. Personal Communication with APCA Information Center.

American Lung Association (ALA). 1982. Position on Indoor Air Pollution. New York, NY.

Americans for Nonsmokers' Rights (ANR). No date. Model Clean Indoor Air Act. Berkeley, CA.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). No date. Improving the Quality of Life. ASHRAE. Atlanta, GA.

American Society of Testing and Materials (ASTM). 1988. ASTM Technical Books Catalog. Philadelphia. ASTM Information Center, Personal Communication.

Barron L. 1985. Home Ventilation Institute. Personal Communication. (Letter to David Mudarri, EPA, dated November 6, 1985.)

Bernstein R.S., Falk H., Turner D.R., Melius J.M. 1984. Nonoccupational Exposures to Indoor Air Pollutants: A Survey of State Programs and Practices. American Journal of Public Health. 74:1020-1023.

Bevirt D. 1988. Sheet Metal and Air Conditioning Contractors National Association (SMACNA). Personal Communication.

California Occupational Safety and Health Standards Board (COSHSB). 1986. Standards Presentation. New Section 5142. Control by Ventilation.

Domarcki AJ. 1984. Emerging Energy Conservation Policy and Regulatory Issues in New York State. Indoor Air '84. 1:213-218.

Environmental Protection Agency (EPA). 1987. Summary of State Radon Programs. Office of Radiation Programs. EPA 520/1-87-17-1. Washington, D.C.

Freund A. 1987. Development of a New Jersey Indoor Air Quality Standard. Proceedings of the ASHRAE Conference, IAQ 87: Practical Control of Indoor Air Problems. pp. 21-32. Arlington, VA.

Gas Research Institute (GRI). 1986. Gas Research Institute Digest. Fall 1986. p.23 and 32-33.

Gas Research Institute (GRI). 1985. Gas Research Institute Digest. Fall 1985. p.20.

General Services Administration (GSA). 1987. Draft Policy Statement. October 30, 1987.

GEOMET. 1987. A Brief Reconnaissance of Private Sector Involvement in Indoor Air Quality. Germantown, MD.

Hardwood Plywood Manufacturers Association (HPMA). 1987. Voluntary Standard. HPMA FE-86. Voluntary Standard for Formaldehyde Emissions from Hardwood Wall Paneling, Wood Composition Board Wall Paneling and Industrial Panels having Face Veneers. February 19, 1987.

Hayward S. 1988. Air and Industrial Hygiene Lab. California Department of Health. Personal Communication.

Helm A. 1988. National Council for Clean Indoor Air. Personal Communication.

Kerwin L. 1986. Opening Address. Proceedings of an APCA Specialty Conference, Indoor Air Quality in Cold Climates: Hazards and Abatement Measures. Walkinshaw D.S. (Ed). APCA.

Llewellyn J.W., Warren P.R. 1986. Regulatory Aspects of Indoor Air Quality - A U.K. View. Proceedings of an APCA Specialty Conference, Indoor Air Quality in Cold Climates: Hazards and Abatement Measures. pp. 478-487.

Maryland State Department of Education (MSDE). 1987. Indoor Air Quality, Maryland Public Schools.

Massachusetts Special Commission on Indoor Air Pollution (MSCIAP). 1987. Minutes of September 30, 1987 meeting.

Miller S. 1988. New Jersey Department of Health. Personal Communication.

Morey P., Otten J., Burge H., Chatigny M., Feeley J., LaForce F.M., Peterson K. 1986. ACGIH Committee Activities and Reports. Bioaerosols: Airborne Viable Microorganisms in Office Environments: Sampling Protocol and Analytical Procedures. Applied Industrial Health. April 1986.

National Environmental Balancing Bureau (NEBB). No date. Publications List. Vienna, VA.

National Institute of Building Sciences (NIBS). 1986. Standards, Regulations, and Other Technical Criteria Related to Indoor Air Quality. National Institute of Building Sciences. Washington, D.C.

Neilander DK, Sacarto DM. 1988. State Asbestos Programs Related to the Asbestos Hazard and Exposure Reduction Act: A Survey of State Laws and Regulations. National Conference of State Legislatures. Denver, CO.

New Jersey Department of Health (NJDH). no date. Proposed Standard Ventilation and Air Quality for Public Buildings and Places of Employment for Public Employees.

Oatman L. 1988. Minnesota Department of Health. Health Risk Assessment Branch. Personal Communication.

Przybylski F.J. 1988. Underwriter's Laboratory. Personal Communication.

Scanlon T. 1987. CPSC's Role in Indoor Air Issues. Indoor Air Pollution Law Report. October 1987.

Shurb RW. 1986. The Canadian UFFI Assistance Program. pp. 496-503. Proceedings of an APCA Specialty Conference, Indoor Air Quality in Cold Climates: Hazards and Abatement Measures. Walkinshaw D.S. (Ed). APCA.

Stolwijk J. 1988. Chairman, Department of Epidemiology and Public Health, Yale University, School of Medicine. Personal Communication.

Tinkleman M. 1988. Presentation at CIAQ. April 26, 1988.

Tobacco Free Young America Project (TFYA). 1987. State Legislated Action on Clean Indoor Air, Cigarette Excise Taxes, and Sales of Cigarettes to Minors. Revised October 1987. Tobacco Free Young America Project. Washington, D.C.

Tobacco Free Young America Project (TFYA). 1988. Update to State Legislated Action on Clean Indoor Air, Cigarette Excise Taxes, and Sales of Cigarettes to Minors. January 1988. Tobacco Free Young America Project. Washington, D.C.

Walkinshaw D. 1988. Office Coordinator. Indoor Air Program. Ministry of Health and Welfare Canada. Personal Communication.

Weiss S. 1988. Consumer Federation of America. Personal Communication.

Wesolowski J.J., Sexton K., Liu K., Twiss S. 1984. The California Indoor Air Quality Program: an Integrated Approach. Indoor Air '84. 1:219-275.

Wisconsin Department of Health and Social Services (WDHSS). No date. Formaldehyde in the Home. Division of Health.

Woods J.E. 1988. Senior Engineer. Honeywell, Inc. Personal Communication.

World Health Organization (WHO). 1987. Air Quality Guidelines for Europe. WHO Regional Office for Europe. WHO Regional Publications. European Series, No. 23.

CHAPTER 10 - INDOOR AIR QUALITY POLICY ISSUES

In the EPA Indoor Air Quality Implementation Plan, submitted to Congress in 1987, the Environmental Protection Agency set two objectives for its indoor air program. These general statements could serve well as the goals for all Federal activities related to indoor air quality:

- to adequately characterize and understand the risks to human health which pollutants pose in indoor environments; and
- to reduce those risks by reducing exposure to indoor pollutants through efficient utilization of available resources.

This chapter discusses the major policy choices available to those who must determine what the appropriate Federal activities are to implementing these objectives.

Because indoor air pollution is the product of many diverse sources and is found in many types of buildings,including private residences, it presents policy makers with some particularly thorny policy issues. As described elsewhere in this report, the sources are as diverse as naturally occurring radon; human activities such as smoking and cleaning, pest control, and hobby activities; building materials such as pressed wood products and asbestos-containing materials; and combustion devices such as unvented space heaters and stoves, furnaces, and fireplaces. In addition to chemical pollutants, there are also biological pollutants. Indoor air quality problems can arise in homes, office and other public buildings, and schools.

There are many abatement techniques that may prove effective, depending on the particular indoor air pollutants and building types. In some cases, improved ventilation may be effective while in other cases, reduction of pollutants may best be achieved by the banning or redesign of products brought into buildings and materials used in constructing buildings. In yet other cases, changes in the behavior of building occupants may bring about the most effective reduction in pollutant concentrations.

There are a variety of control and prevention actions that the Federal government could take to address the risks from indoor air pollution. Many of them can be pursued in either a regulatory or a nonregulatory manner. As policies are formulated, decision-makers can choose any of the options singly or in combination. This fact is particularly important in light of the fact that some options are "pollutant-by-pollutant" strategies and others are "multi-pollutant" strategies.

To select and implement any of the options effectively will require a Federal indoor air research program. Volume III of this Report to Congress is devoted to a discussion of the indoor air research needs that have been identified by EPA and other Federal agencies.

The options discussed below are:

- setting standards for
  - individual indoor air pollutants or mixtures of pollutants;
  - design, operation, and maintenance of ventilation systems; and
  - products brought into buildings;
- providing guidance on identifying, correcting, and preventing indoor air quality problems in new and existing buildings; and
- establishing public information and technical assistance programs.

10.1 SETTING STANDARDS

Establishing Pollutant Standards

Establishing limits on levels of individual pollutants that will protect public health or welfare is often a basic component of environmental programs. Whether or not to establish such limits for the large number of pollutants found in indoor air is a basic policy decision. Indoor air quality standards could be established as either enforceable limits, as part of a regulatory program, or as recommended limits, as part of a nonregulatory program.

There are a number of reasons why it is advisable to examine what role, if any, indoor air quality standards should play in a federal indoor air quality program. The considerations listed below may argue for not setting such standards at all or for setting recommended limits (or "guidance") instead of enforceable standards.

Number of pollutants of concern: There are hundreds of indoor air pollutants. However, little information is available about how many are potentially harmful, or about the levels found indoors and their associated health effects. Putting an emphasis on indoor air standards will necessarily require the expenditure of significant resources and would foster a pollutant-by-pollutant approach to improving indoor air quality.

Availability of multi-pollutant strategies: Since indoor air quality problems by definition emerge in enclosed spaces, it will be possible to effectively address some problems by changing the ventilation rate or by air cleaning. Ventilation and air-cleaning, which are discussed in more detail in one of the following policy options, are multi-pollutant strategies.

Applicability of standards to residences: Traditionally there have been sharp distinctions between setting standards or guidance for private homes as opposed to public spaces such as offices and public buildings. The EPA radon program established guidance -- in the form of an action level -- not an enforceable standard for reducing the risks of radon, when radon concentrations in homes were found to be a significant health risk.

Health or combination of health and technological basis: The principal argument for setting a purely health based standard is that it gives the public a clear message about the level that are thought, given current scientific evidence, to protect health. The principal argument for setting a standard that is based on some combination of health and technical feasibility is that such a standard will motivate more action because it is demonstrated to be an attainable goal. Attaining standards that are strictly health based, on the other hand, may require measures that are technically infeasible or economically prohibitive. For example, if a health-based standard for a carcinogen were to be completely protective of all risk, it would have to be zero because carcinogens at any level are expected to pose some risk to public health.

Availability of monitoring equipment and mitigation techniques: Standards for individual pollutants are useful only if effective monitoring equipment and feasible mitigation techniques have been identified. If policy makers determine that setting pollutant standards or guidance is an appropriate role for the Federal government, they will need to build a supplementary program devoted to developing reasonably-priced, easy-to-use, dependable monitoring equipment (or evaluating available monitoring equipment) and to assessing the effectiveness of prevention and control measures.

Health Advisories

Issuing health advisories on specific pollutants or mixtures of pollutants can be a supplement or alternative to setting standards. They would describe a range of potential effects at a range of concentrations. If standards have been set, the advisories would include them. To be most useful, the contents of such advisories should include information on mitigation measures as well as potential health effects and should be written in language appropriate to the targeted audience.

Setting Standards for the Design, Operation, and Maintenance of Ventilation Systems

Ventilation standards have historically been developed with an eye to maximizing thermal comfort and, since the energy crisis of the 1970's, to conserving energy. Altering ventilation standards offers a promising "multi-pollutant" option to preventing the simultaneous build-up of many pollutants. Air cleaning, if found to be an effective mitigation technique, may be used in combination with ventilation strategies to reduce pollutant levels. Work done to date suggests that increasing ventilation rates need not come at the expense of undoing efforts to conserve energy, but it is likely that policy-makers will want to do further analysis of the impact of increasing ventilation rates on energy consumption.

The American Society for Heating, Refrigerating, and Air-Conditioning Engineers, a private standard-setting organization, has taken the lead in establishing ventilation standards on a "consensus" basis. Private sector groups affected by the decision have worked with others including research professionals and government officials in writing these standards. Model building code organizations and State and local government code agencies rely heavily on the ASHRAE standards as they set model codes and enforceable state and local codes, respectively.

Individuals from the Federal government with expertise in ventilation and indoor air quality have served as members of the committees developing these standards. A possible direction for the Federal government is to play a more active role in the development of future ventilation standards. Two types of ventilation standards are possible: Those for the design of ventilation systems, and those for system maintenance and operation.

Standards for the Design of Ventilation Systems

Drawing on the expertise of people in the public and private sector, the Federal government could set a national indoor air quality standard or guidance policy that prescribed particular ventilation design features, or it could work more actively with ASHRAE, the model code organizations, and others as the ventilation standard is revised in the future. Any effort to write such a standard would have to include, at a minimum, all the groups that participate in the development of the ASHRAE standards.

Standards for the Operation and Maintenance of Ventilation Systems

Virtually all ventilation standards govern only the design of new systems as they are installed in new buildings. Substantial indoor air quality problems arise from the improper maintenance or operation of these systems once the building is occupied and in use. One state, California, has recently developed a set of enforceable requirements for the operation and management of ventilation systems in workplaces under the State's jurisdiction; it is too soon, however, to judge the potential effectiveness of these requirements. In addition to, or as an alternative to, setting standards for the design of ventilation systems, the Federal government could set a national standard or guidance policy for the operation and maintenance of ventilation systems or it could work actively with ASHRAE, the model code organizations, and others for the development of such standards.

Public participation and public debate would be an important element in the development of any policy guidance even if the process did not fall under the Administrative Procedures Act requirements for public notice and comment.

Actions taken by ventilation operators and building managers often have important ramifications for indoor air quality, yet individuals within these groups are given little opportunity for increasing their knowledge about the interconnections between ventilation and indoor air pollution. The Federal government could develop training materials and technical assistance projects for people managing buildings and operating ventilation systems in conjunction with trade and union organizations. (This is one example of the type of activities that could be part of a public information and technical assistance program described in Section 10.3 below.)

Setting Product Standards

Controlling indoor air pollution by setting standards that affect the sale, manufacture, or use of products that are sources of indoor air pollution is another potentially important mitigation option. Existing statutes such as the Consumer Product Safety Act, the Toxic Substances Control Act, and the Federal Insecticide, Fungicide, and Rodenticide Act authorize Federal agencies to set standards. See Chapter 8 for a discussion of these laws.

Federal agencies have already set some product standards for the purpose of enhancing indoor air quality. For example, EPA has banned the use of asbestos in certain building materials and is developing additional rules concerning asbestos-containing products and CPSC has banned the use of asbestos in spackling compounds and artificial fireplace logs, and requires hazard and use labelling of asbestos containing products. CPSC has also banned the use of vinyl chloride in consumer aerosol products. EPA has also prohibited indoor uses of several pesticides: manufacturers are prohibited from using lindane in indoor fumigating devices; homebuilders are prohibited from using logs treated with pentachlorophenol in log home construction; and all other indoor applications of pentachlorophenol and creosote are also forbidden.

Given the thousands of products that are used inside buildings, however, it is clear that only a small proportion have been regulated under existing laws. One choice open to policy-makers is, therefore, to place additional emphasis on setting either mandatory or voluntary standards on such products.

Product Advisories

On some occasions, Federal agencies have issued product advisories or alerts to the public. For example, EPA has entered into an agreement with manufacturers of wood preservatives for the development of a consumer awareness program. CPSC has recently issued a consumer alert on the use and maintenance of room humidifiers. CPSC also recently issued regulations requiring manufacturers of many consumer products containing methylene chloride to put hazard warnings on the product containers. There have been few efforts to evaluate the effectiveness of such consumer alerts, but CPSC is going to assess the impact of the methylene chloride alert over the next three years. Increasing the emphasis on such consumer alerts is an option for a Federal indoor air program that seeks to address indoor air quality problems through attention to specific products.

10.2 PROVIDING GUIDANCE ON MEASURES TO IDENTIFY, CORRECT, AND PREVENT INDOOR AIR QUALITY PROBLEMS IN NEW AND EXISTING BUILDINGS

Providing Guidance for Existing Buildings

Buildings are identified as potentially having an indoor air quality problem when a large number of occupants complain of health problems or when occupants contract a identifiable disease that is transmitted via the indoor air. Since the number of such buildings is on the increase, the problem of indoor air quality complaints in public buildings (sometimes referred to as the "sick building" phenomenon) is growing in importance. Why these complaints arise in some buildings and not in others is still not well understood; however, the demand for public and private sector services to help people correct these types of problems is large and growing.

Addressing indoor air quality problems in buildings with large numbers of occupant health complaints is not necessarily a problem of setting and attaining some uniform standards for specific pollutants, although such standards may be appropriate where the cause of the problem can be traced to a specific source or pollutant. It is likely there will never be enough standards to prevent these problems because there are hundreds of pollutants at very low concentrations. Indoor air quality problems may arise from the additive or synergistic effects of these pollutants, as well as from single pollutants. Instead, the immediate need appears to be to decide on appropriate federal actions that will give indoor air quality investigators and building managers the tools to identify and correct these problems.

Most of the understanding about how to conduct indoor air quality building investigations currently resides in the private sector. Within the Federal government, the National Institute for Occupational Safety and Health has the most experience in this field, and other Federal agencies, including EPA and DOE have some experience. Various standard-setting agencies, including the American Society of Testing and Materials and the American Council of Governmental and Industrial Hygienists are considering how they might contribute to the growing body of resource materials for building investigations. There is, however, an opportunity for the Federal government, in conjunction with other public and private sector groups, to develop some commonly-accepted building investigations procedures targeted at both professional investigators and at building managers.

Training and Competency Testing

The next step for Federal, State or local governments could be the development of training programs for building investigators and building managers. Officials in State and local governments might also find such training courses useful. A possible long-range outgrowth of these courses is some type of competency testing for professionals offering building investigation services. Such training and testing programs could decrease the potential for fraud when people employ companies to conduct indoor air quality investigations in buildings.

Providing Guidance for New Buildings

Another frequently-voiced concern is how to prevent indoor air quality problems from occurring in the first place. Considering the need for professional expertise that resides in the private sector about building practices, such a program could be carried out effectively only through close collaboration with professional architecture, design, and construction associations.

Providing guidance on how to prevent indoor air quality problems in new buildings could entail many activities from the publication of materials that describe recommended construction techniques to the preparation of training courses. A logical extension of providing such guidance would be to work with private sector model code associations to incorporate these design features as part of local and State building codes. EPA's work in assisting the model code organizations as they write model codes for radon prevention in one and two-family dwellings is an example of how the federal government can work directly with model code organizations.

10.3 ESTABLISHING PUBLIC INFORMATION AND TECHNICAL ASSISTANCE PROGRAMS

While limited to single pollutants and focusing on one type of building, at least initially, the asbestos and radon programs within EPA have given the Agency experience in developing indoor air quality information and technical assistance programs. From these programs, EPA has learned much about developing cooperative partnerships with State agencies, targeting information at specific audiences (e.g., school districts, homebuilders, building contractors), and developing joint projects with private sector organizations. Other agencies also have valuable experience in the conduct of information and technical assistance programs. A public information program could involve one or more of the following elements:

Developing and Disseminating Information to the Public

There are not many materials on indoor air quality issues for the general public at present. Increased emphasis on transferring information to the general public could be one component of a larger Federal role in indoor air.

A few private sector organizations, such as the American Lung Association and the Consumer Federation of America, have been actively involved in developing and disseminating indoor air information to the public. Some Federal agencies, including the Consumer Product Safety Commission and EPA, have written brochures on asbestos and radon. The Department of Energy has also developed some indoor air quality information.

This past year the EPA Indoor Air Division published two pieces for the non-technical public: A Directory of State Indoor Air Contacts and The Inside Story: A Guide to Indoor Air Quality. Other indoor air publications for more technical audiences are in preparation.

Establishing an Information Clearinghouse

An information clearinghouse differs from a program that simply develops and disseminates informational materials because it provides a central place where people can get answers to specific questions. There are a number of clearinghouses or hotlines run by EPA and other Federal agencies that could be used as possible models for an indoor air quality clearinghouse. It is most important that both the purpose and the targeted audience be clearly specified (e.g. State and local governments, industry, public interest organizations, the general public) and that the clearinghouse be formed with adequate participation from the targeted groups.

Developing Technical Assistance Programs With Targeted Groups

There are many groups with power to effect indoor air quality -- to name a few, homebuilders, building owners and managers, architects and engineers, many agencies within State and local governments, industries offering investigative and remedial services, and the general public. To improve indoor air quality will require informed actions by many of these groups. Technical assistance, delivered through such vehicles as regional training centers, joint government/industry ventures, and readily accessible training courses are potential means of accomplishing the goal of information dissemination. EPA has learned much about how to develop and disseminate technical guidance on indoor air problems from its radon and asbestos programs.

Building the Capacity of State and Local Governments

The prime contact point for the public on indoor air quality issues is appropriately the agencies in State and local governments. A Federal indoor air quality program could therefore include actions to develop requisite knowledge at the State and local government level, including those that allow States to learn from one another. Key elements to achieving such a goal are likely to be activities to promote information exchange among States and to encourage the development of model State programs. All the steps that the Federal government takes to develop standards, guidance, and informational materials are likely to enhance State efforts to address similar problems. Financial assistance, in the form of pilot programs, demonstration projects, and grant programs, is also viewed by most States as a critically-needed component of a Federal response to indoor air quality problems.

10.4 SUMMARY

There are many potential actions that the Federal government could take to address the problem of indoor air pollution, as this chapter demonstrates. The first set of options described above would set different types of standards or guidance, pertaining to indoor air pollutant concentration levels, ventilation system design and operation practices, or product composition, function, and use. The second set of options would provide guidance to the public, including targeted technical audiences, about methods to identify, correct, and prevent indoor air problems. The third option listed components of a public information and technical assistance program. Within each option, there are many possibilities for Federal participation because a successful response to these problems must ultimately include active interaction between all levels of government and many groups within the private sector.

U. S. GOVERNMENT PRINTING OFFICE 1989/617-003/04926